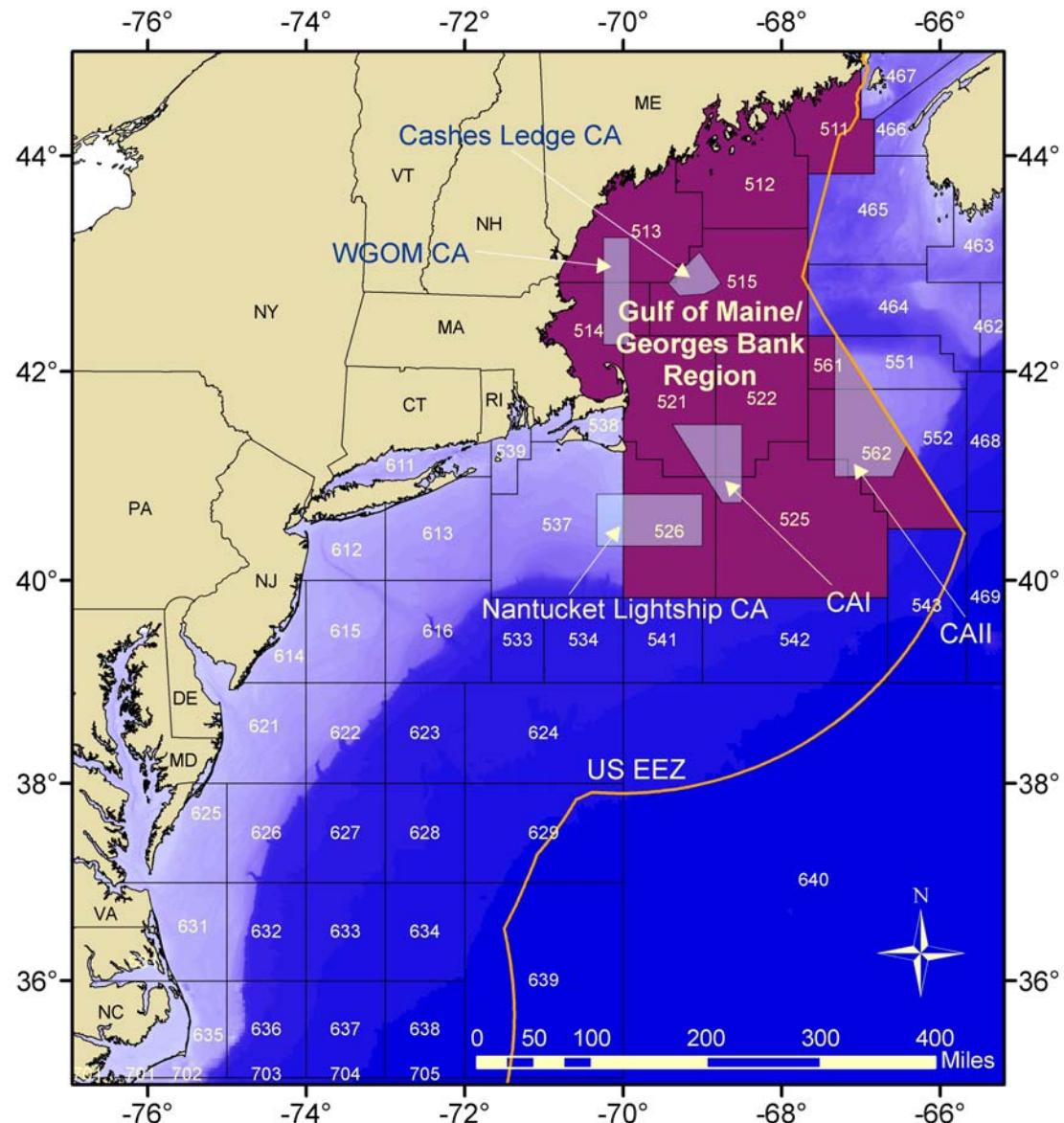


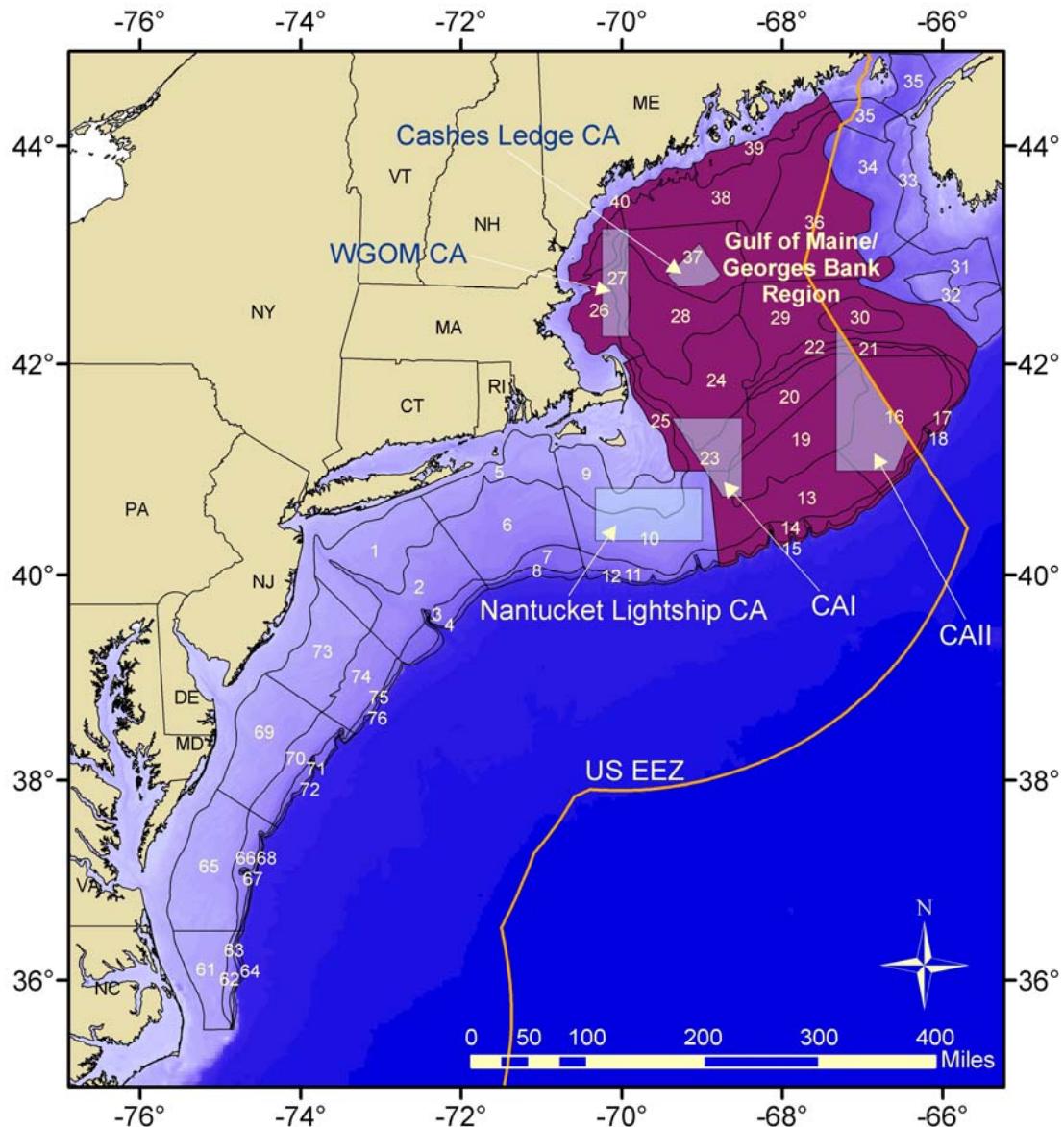
Atlantic Halibut (*Hippoglossus hippoglossus*)



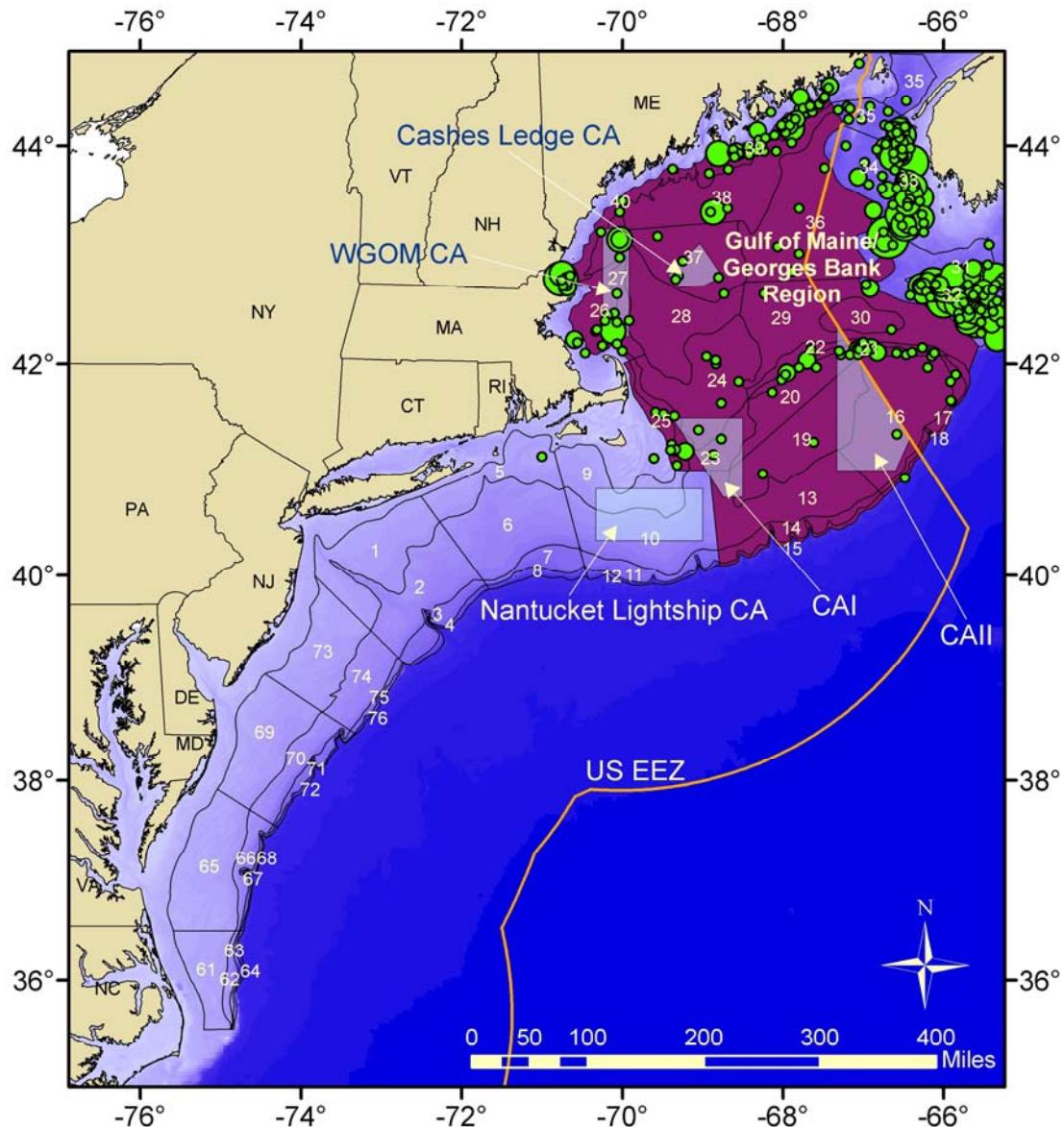
Laurel Col
Northeast Fisheries Science Center



Statistical areas used to define the Gulf of Maine/Georges Bank region
of the Atlantic halibut stock.



NEFSC survey strata used to define the Gulf of Maine/Georges Bank region of the Atlantic halibut stock.



NEFSC survey strata used to define the Gulf of Maine/Georges Bank region of the Atlantic halibut stock.

Figure S1. Atlantic halibut landings from the Gulf of Maine-Georges Bank region during 1893-2006.

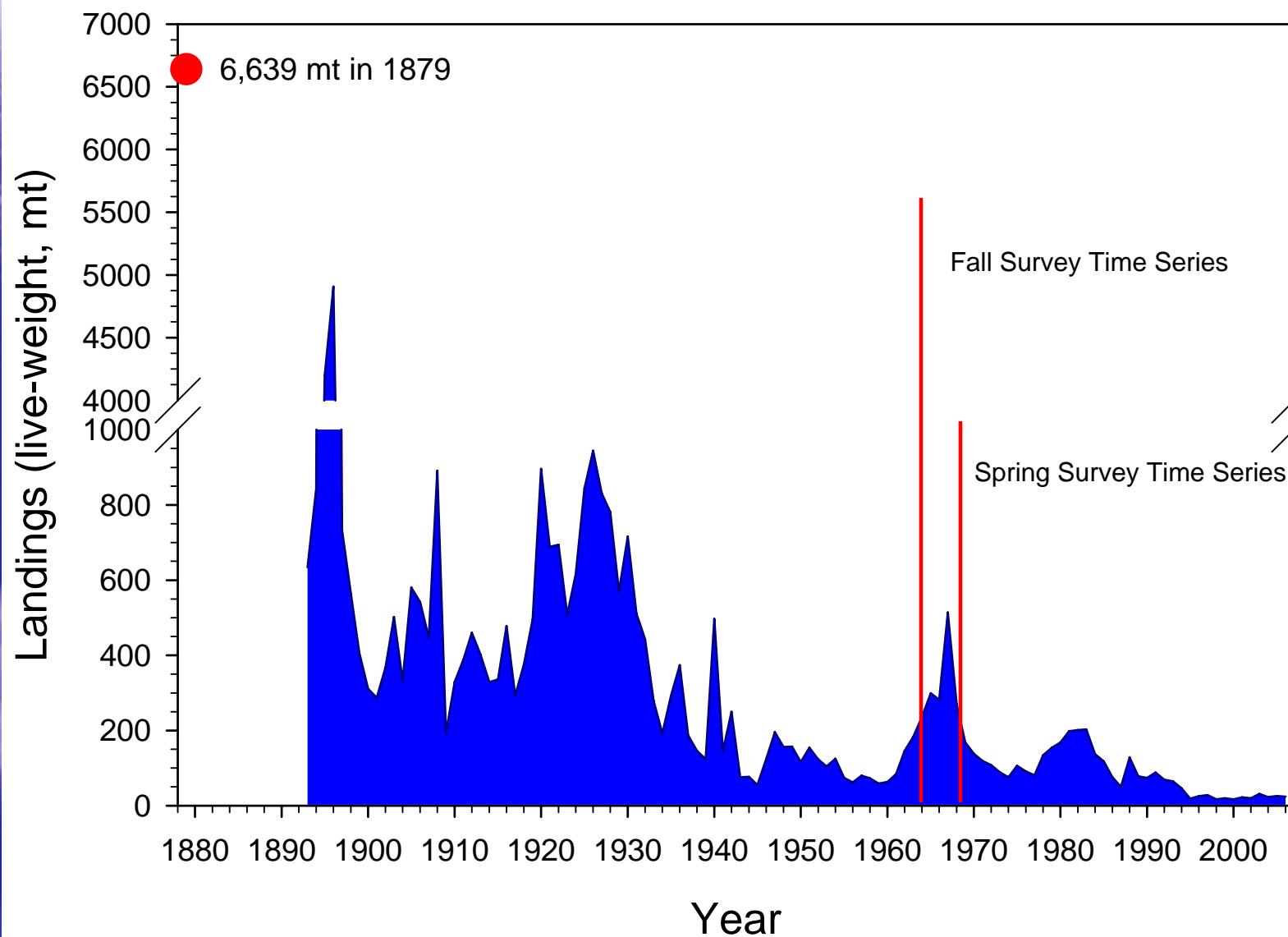


Figure S2. Atlantic halibut US landings (mt) and discards (mt with 95% CI) from combined ratio estimation.

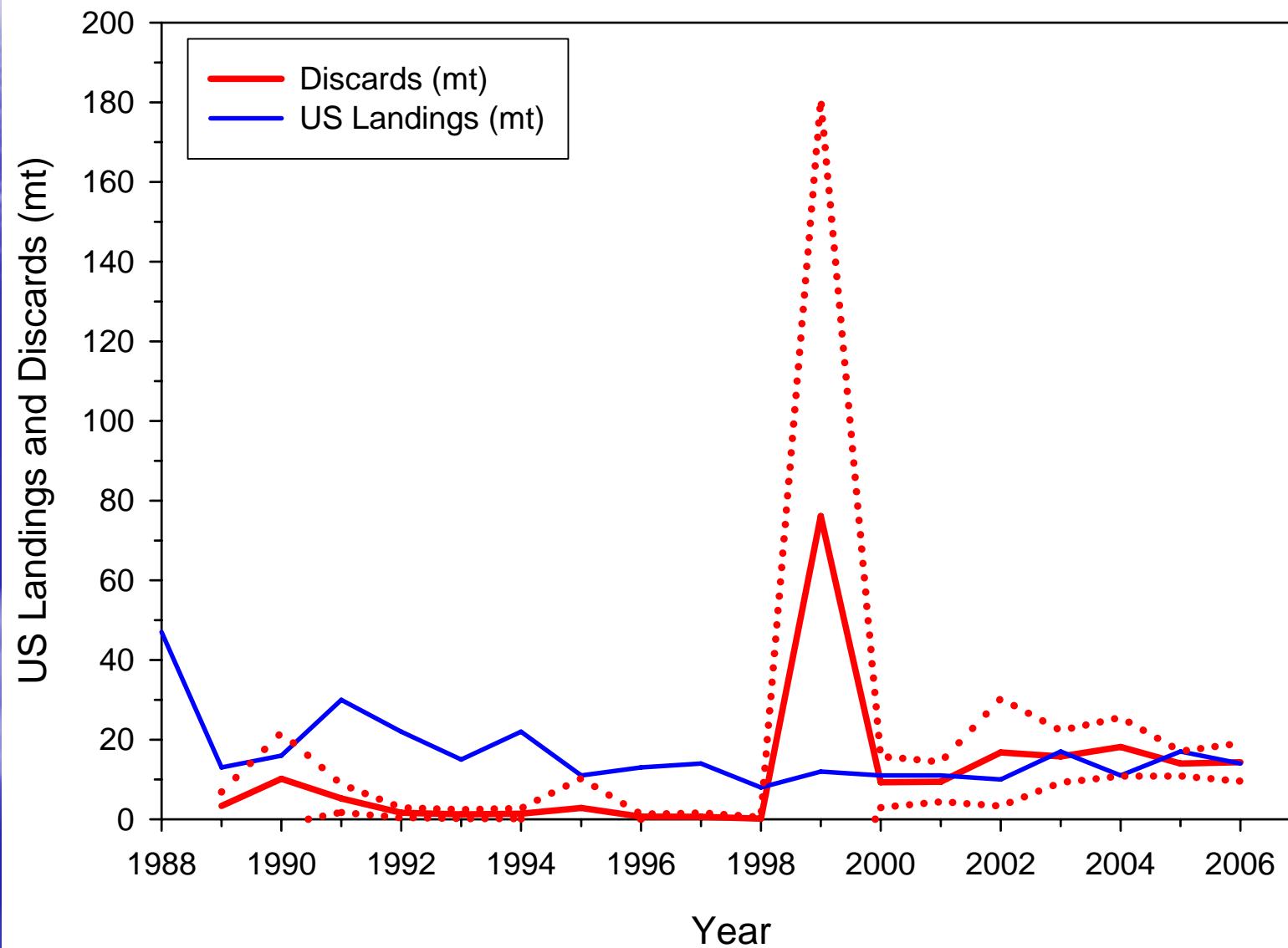
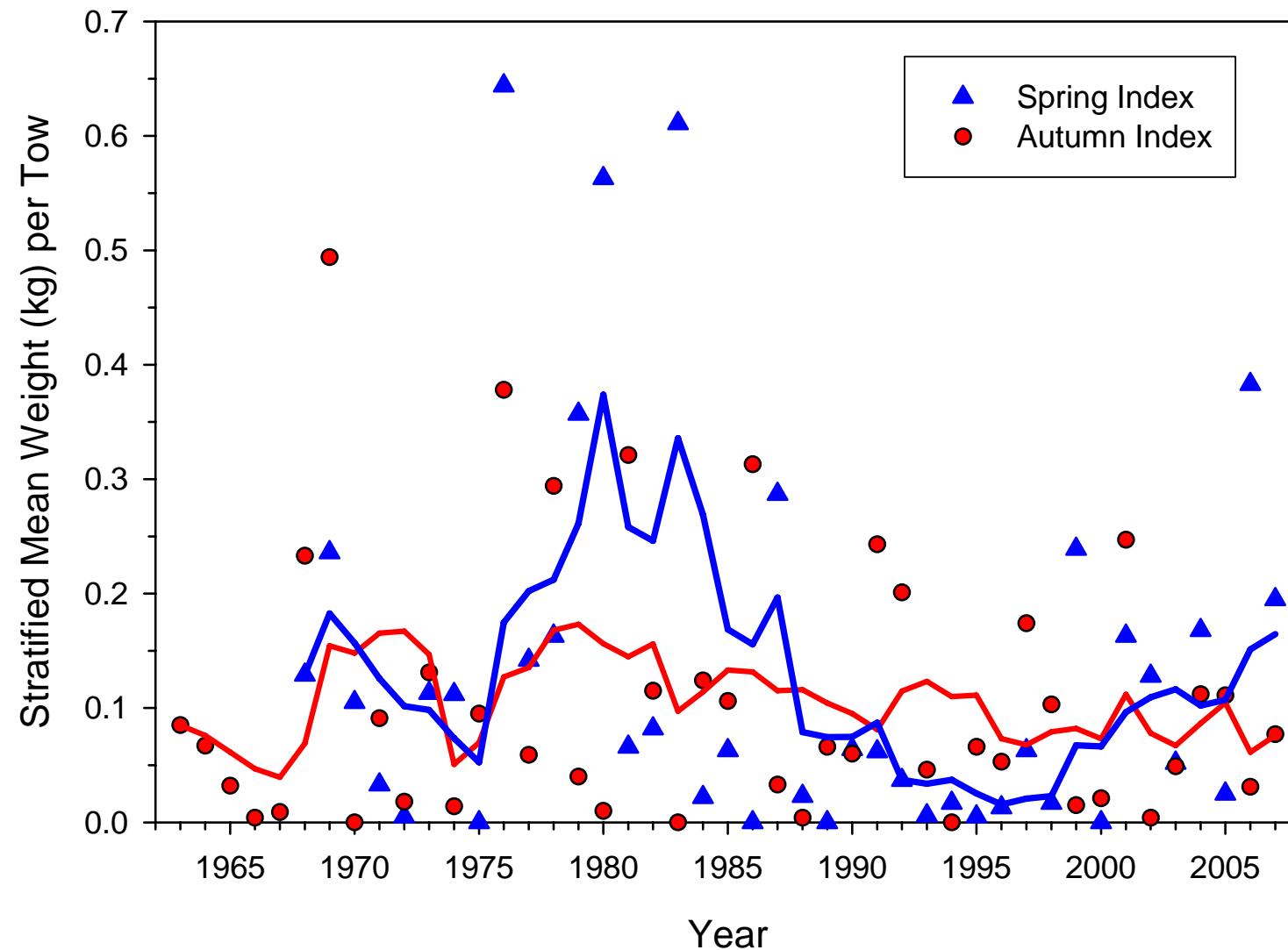
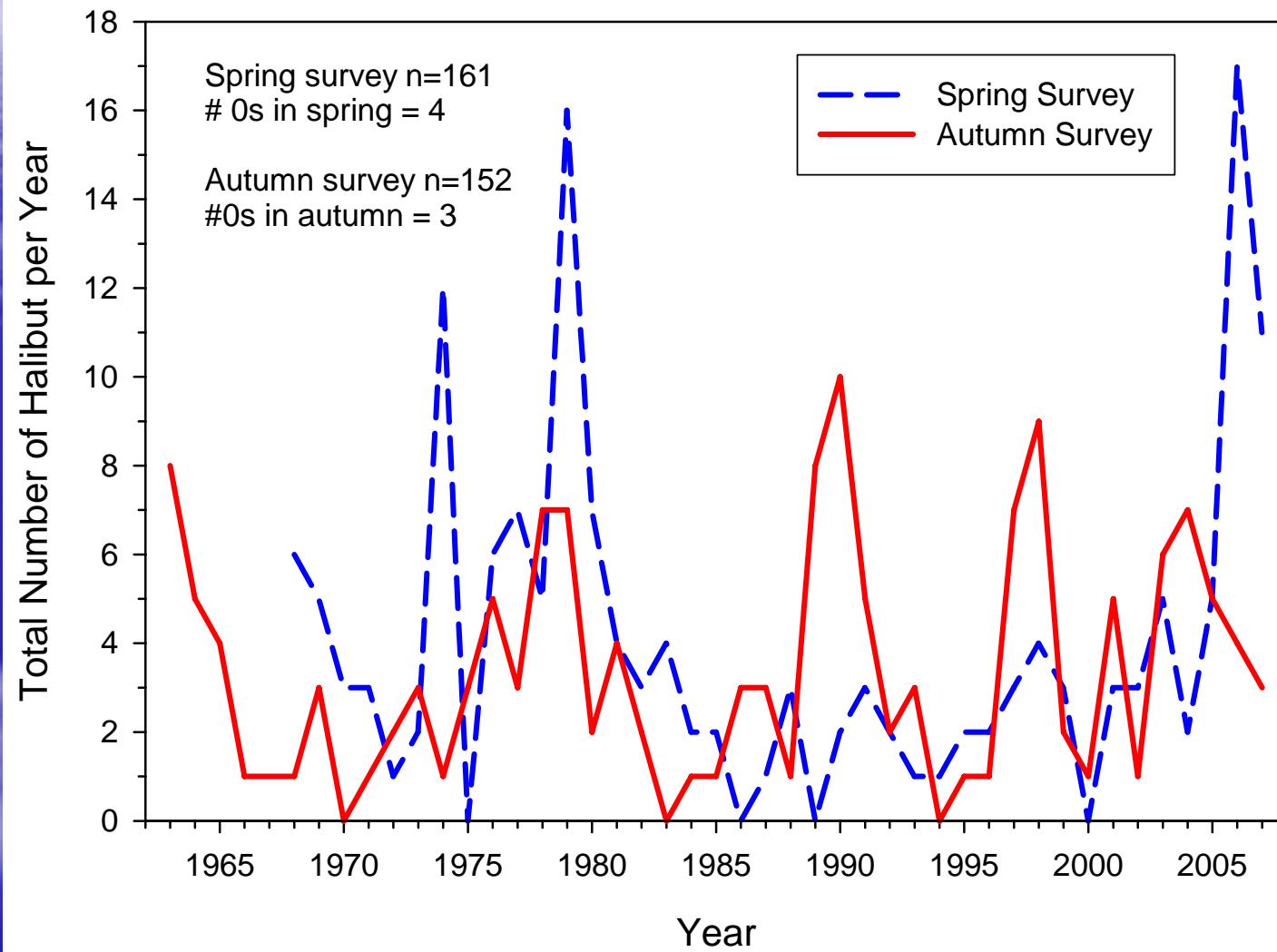


Figure S3. Atlantic halibut biomass indices (stratified mean weight per tow and 5-year average) from NEFSC spring and autumn surveys.



Total numbers of Atlantic halibut caught in NEFSC spring and autumn surveys per year



- No age data available
- No door, vessel or gear conversions available

Atlantic Halibut Current Status and Management

Current Status

- NEFSC: Overfished, Overfishing can not be determined
- NOAA: Species of Concern
- American Fisheries Society: Threatened
- IUCN: Endangered (due to overfishing)

Management

- Northeast Multispecies Fishery Management Plan (Amendment 9) 1999
- 1 fish halibut possession limit per trip for commercial and recreational vessels
- Minimum size of 36 inches (91 cm)

Figure S2. Trends in swept-area biomass indices (mt) of Atlantic halibut from NEFSC autumn bottom trawl surveys.

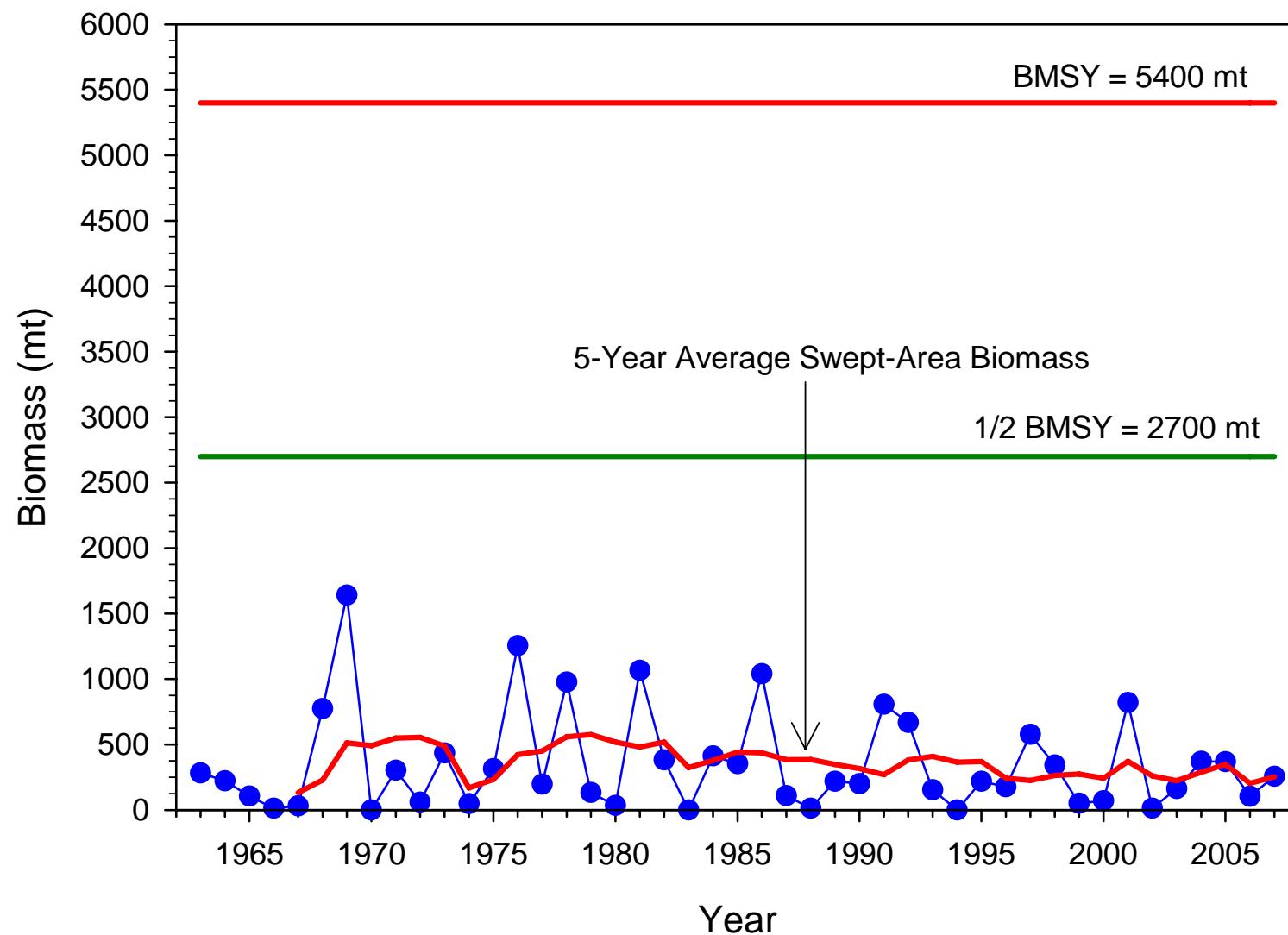
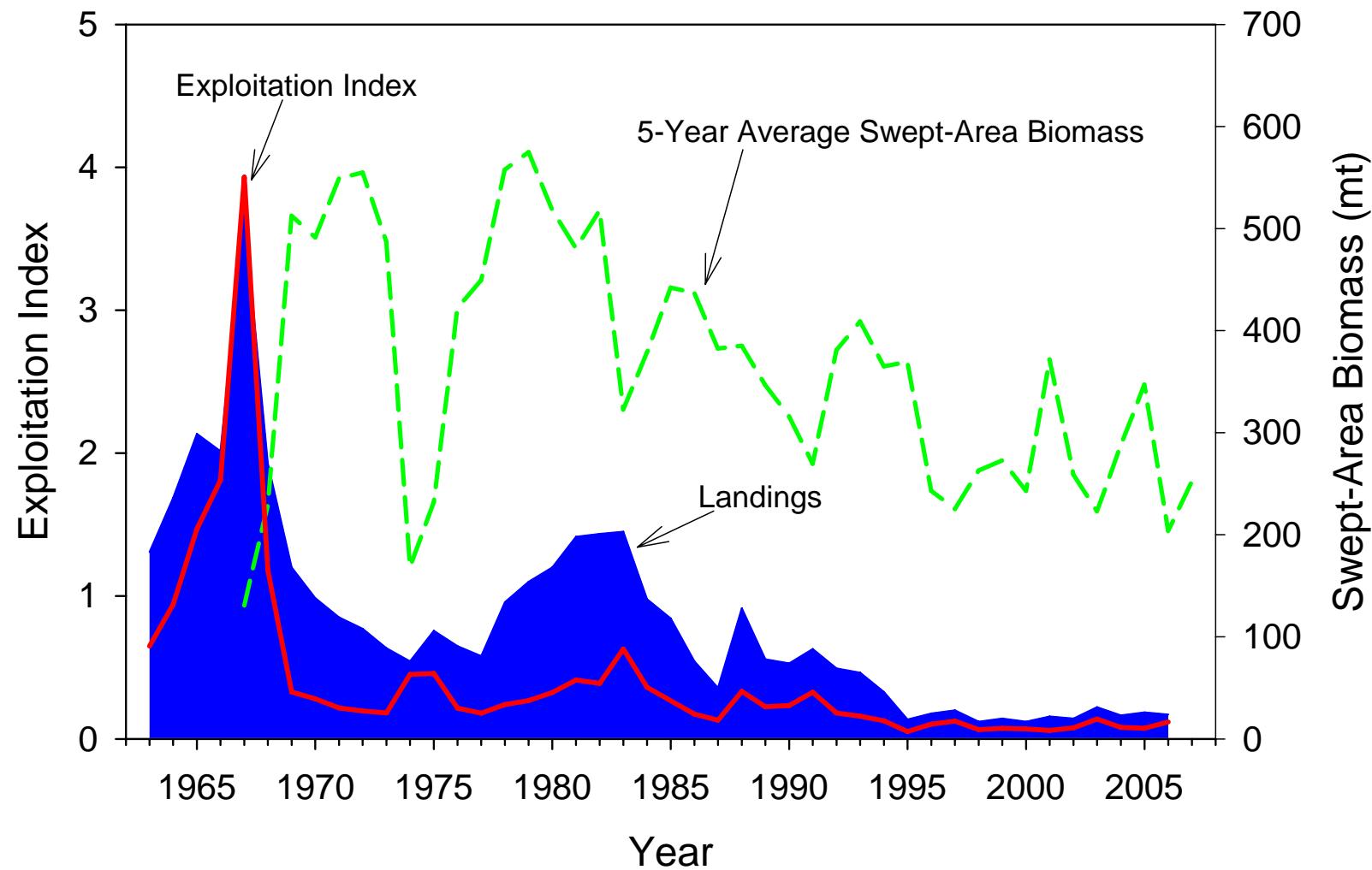


Figure S4. Trends in Atlantic halibut commercial landings, fall stratified swept-area biomass, and exploitation index calculated as annual landings divided by the 5-year moving average of the swept-area biomass index.

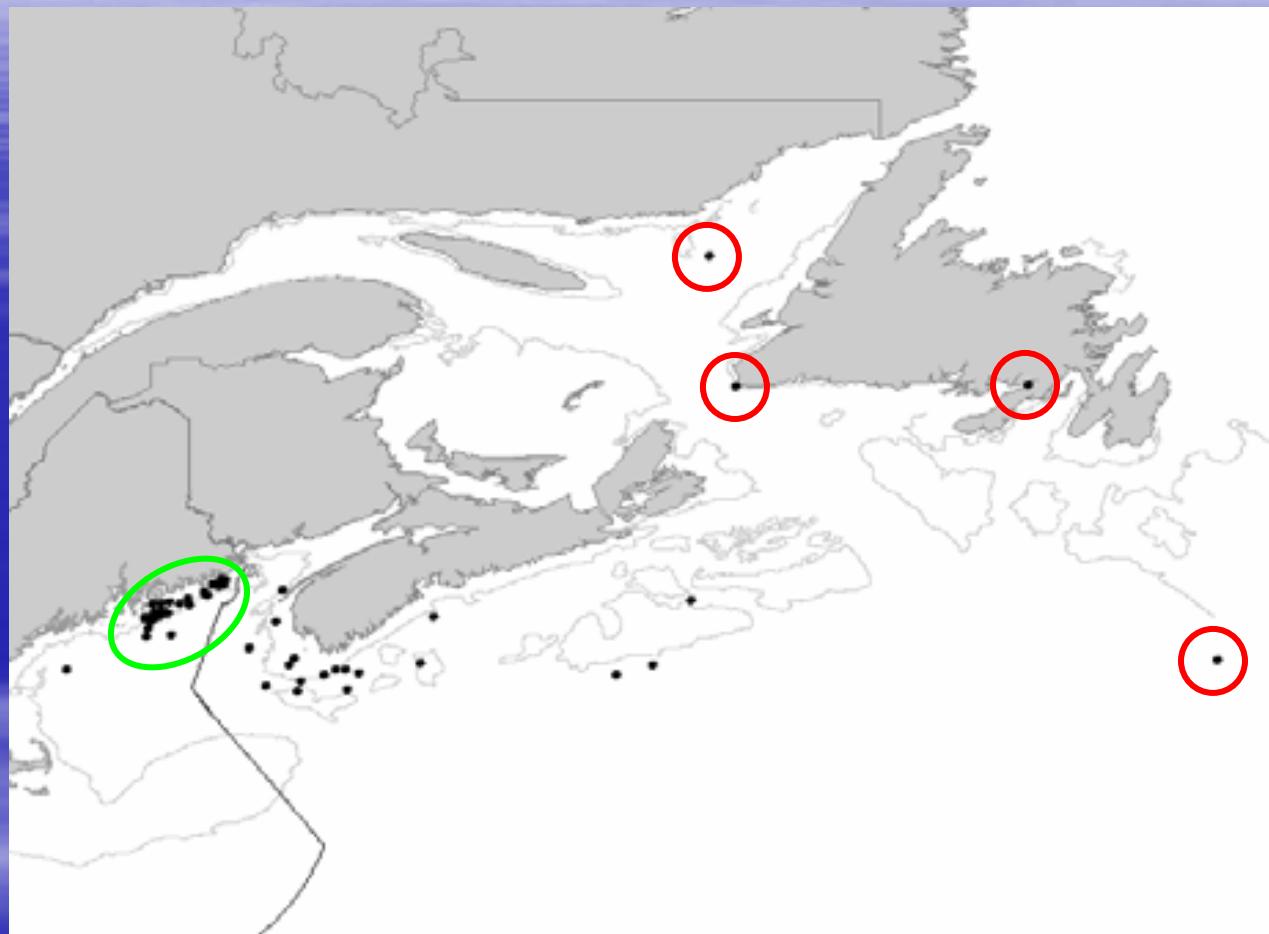


2000-2004 Experimental Halibut Fishery

Maine DMR and Maine Sea Grant

- Tagged 825 halibut in coastal Maine waters
- 1,611 fish retained, otoliths and gonad samples taken
- 92 recaptured as of Dec. 31, 2005 (11% return rate)
- 28% of recaptures in Canadian waters
- Mean days at large = 431
- Mean distance traveled = 151 km (1,758 km max)
- Mean length of tagged halibut = 79 cm (all immature)

Experimental Halibut Fishery



- Release area in green
- Black dots represent recapture locations

Basic Life History Characteristics for Atlantic Halibut

Sigourney et. al. 2006

- Aged 530 otoliths from NMFS surveys and Experimental Halibut fishery
- Halibut up to ~40+ years old
- Longline gear selected fish with faster growth compared to bottom trawl
- $A_{50} = 6.0$ years for males, 7.3 years for females
- $L_{50} = 80.2$ cm for males, 103.0 cm for females

Stock Reduction Analysis

Kimura and Tagart, 1982

- Uses available time series of catch data: C_i (catch in year i)

- For $i = 1, \dots, n$ catch equations:

$$C_i = B_i F_i (1 - \exp(-F_i - M)) / (F_i + M)$$

$$B_i = B_{i-1} \exp(-F_{i-1} - M) + R \text{ for } i > 1$$

- Provide starting estimates for: B_1 and M , solve for R

- Find best estimates of F_i , B_i

- Two equations used for SRA plots:

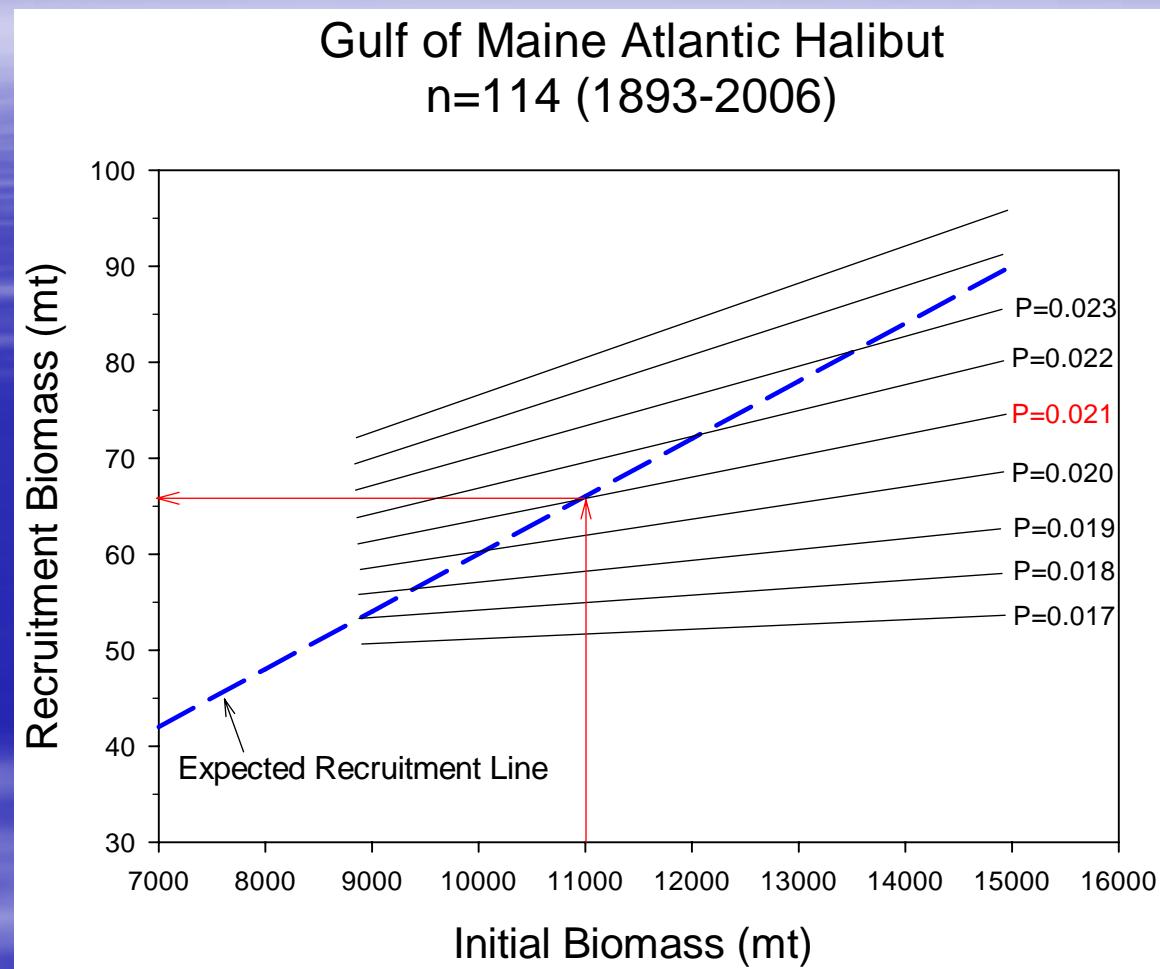
$$P = B_{n+1}/B_1$$

describes the decline in population biomass caused by n years of catches

- Expected recruitment line (for varying values of R and B_1):

$$R = B_1(1 - \exp(-M))$$

Stock Reduction Analysis



- $M = 0.006$ (-log(0.5)/max age 50)
- $B_i = 11,000$ mt (sum of 1893-1897 landings)
- $B_{n+1} = 252$ mt (2007 swept-area biomass)
- Gives $R = 66$ mt

Stock Reduction Analysis

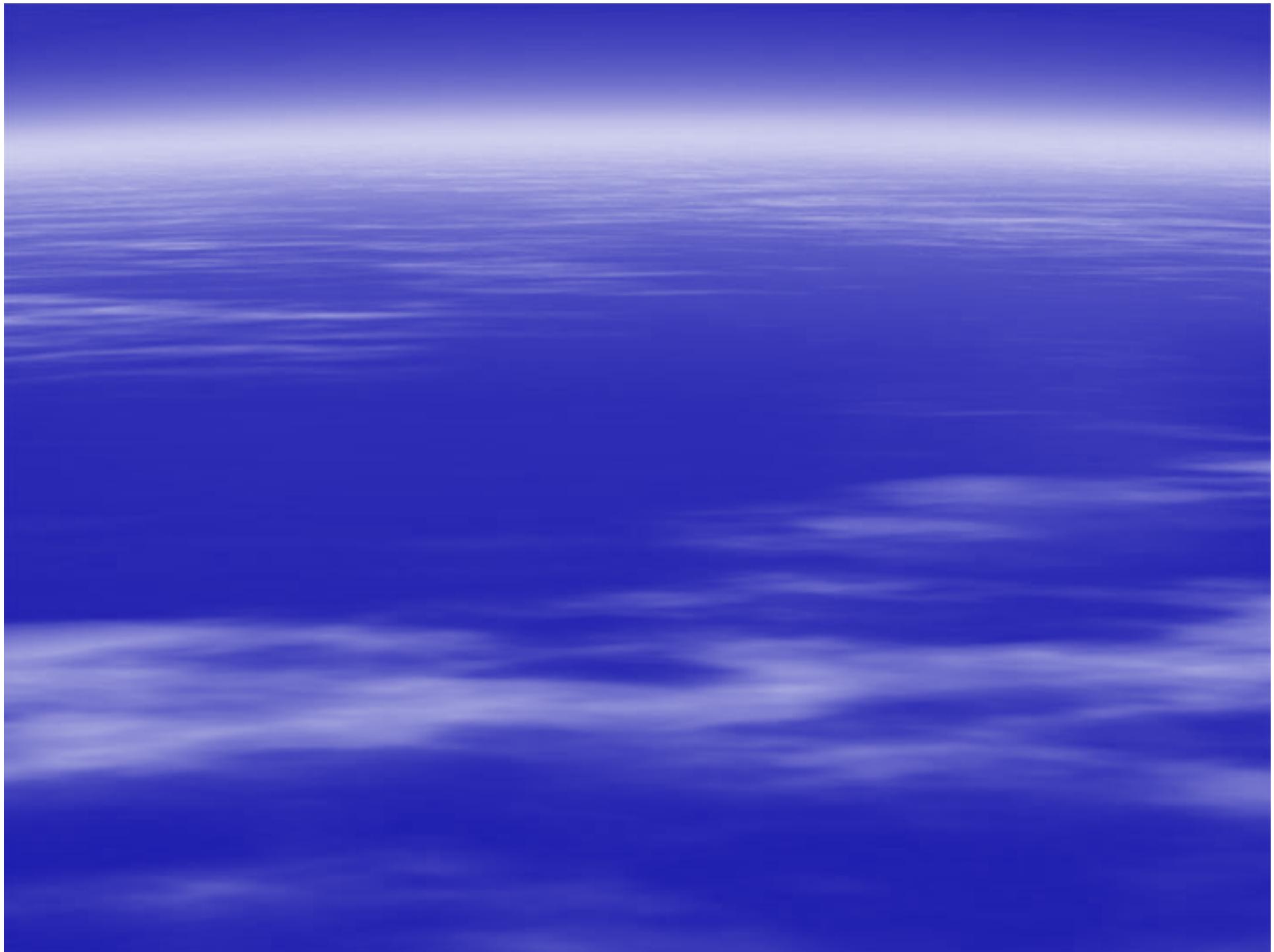
Strengths

- Uses entire catch time series
- Does not rely on surveys (little relation to catches and high uncertainty)
- Very simplistic, no age data required
- Provide annual estimates of F (possibly use to determine overfishing status)
- Immigration or emigration do not violate assumptions of model
 - included in apparent recruitment
- Plots can be used to verify results in relation to other indices/known values
 - Compare to NMFS survey indices, future inshore Maine halibut longline surveys etc.

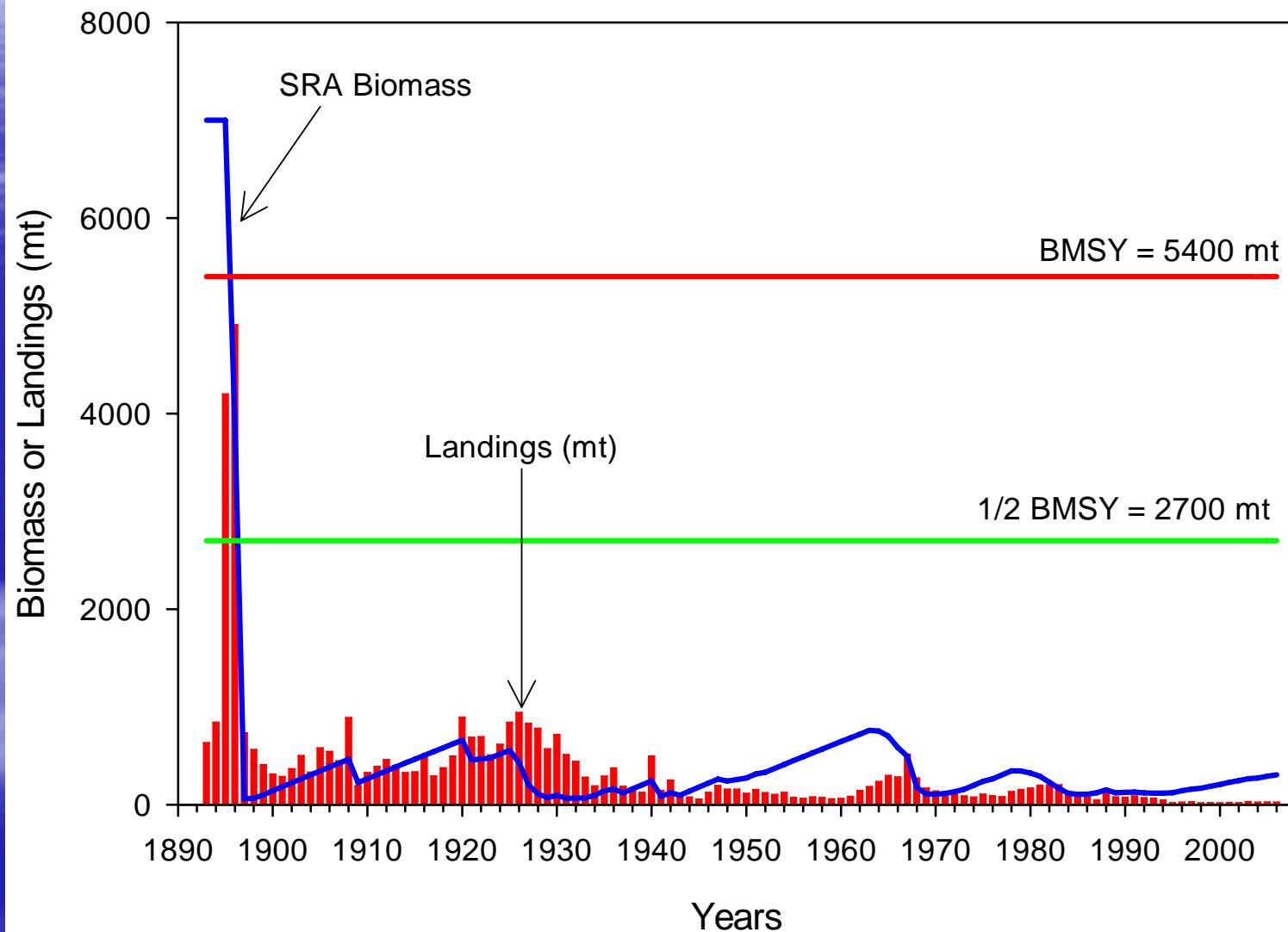
Stock Reduction Analysis

Weaknesses

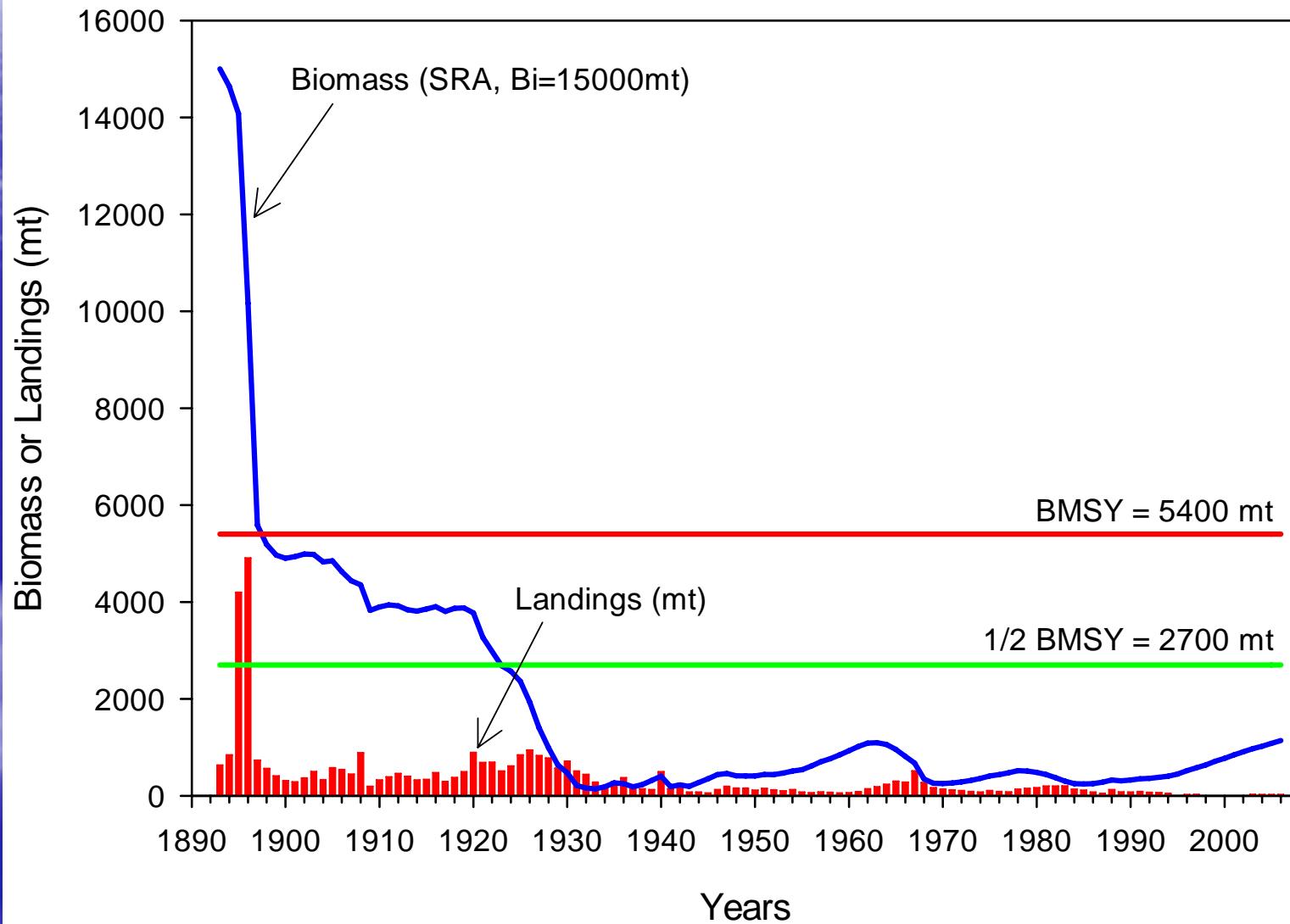
- Not widely used for stock assessments
- Current regulations could skew catch in recent years
 - Incorporate discards?
- Starting estimates very rough for $B_i, F_1, \dots, F_n, M, P$
- M and R are fixed through time
 - R can be variable in more complex versions of the model
- Current model assumes virgin biomass for B_i
 - might be possible include F in initial biomass
- Are assumptions/problems with this approach worse than the fall-back?
 - Any better alternatives?



Atlantic Halibut Biomass from Stock Reduction Analysis

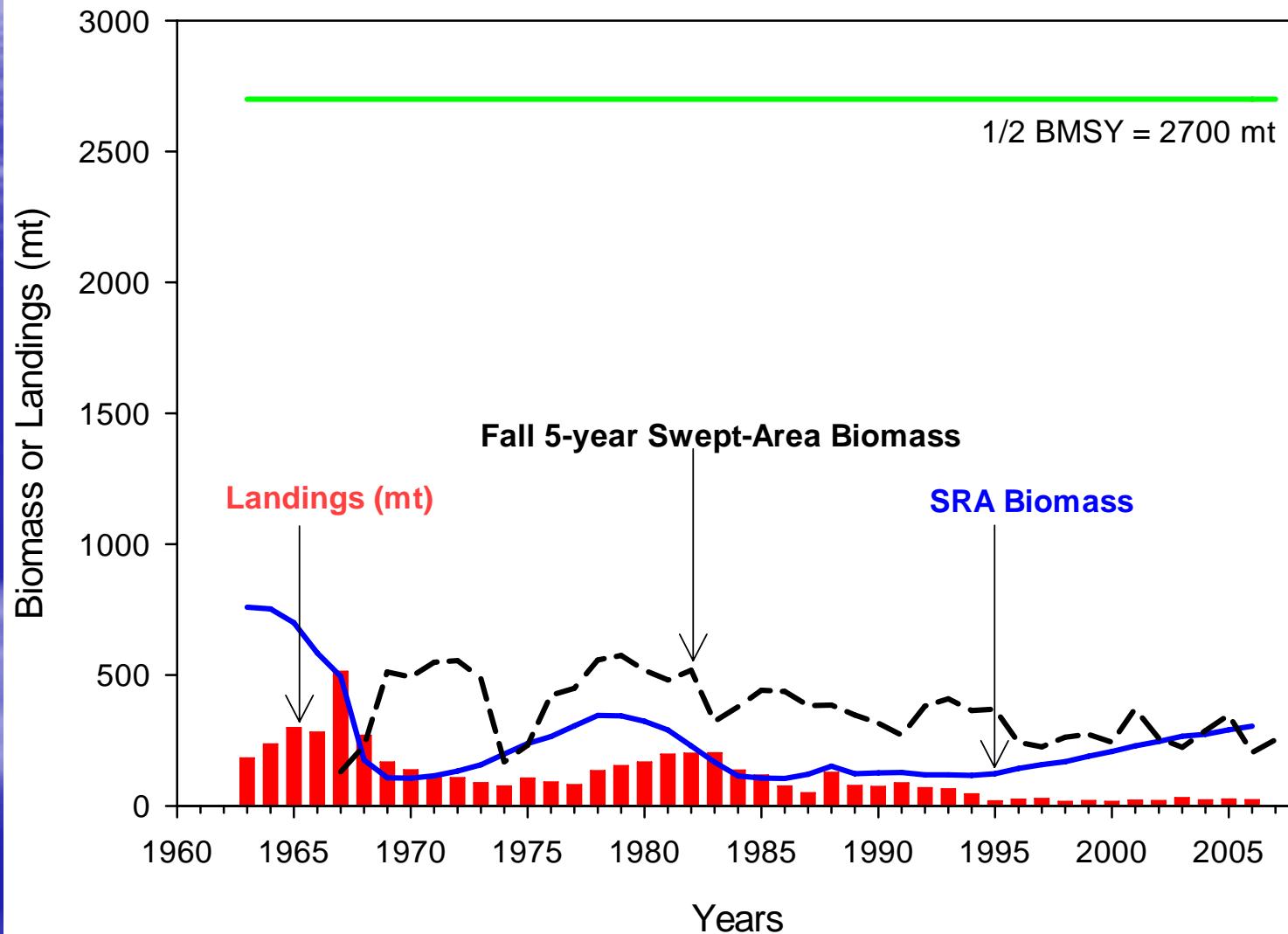
$$B_i = 7000 \text{ mt}$$


Atlantic Halibut Biomass from Stock Reduction Analysis

$$B_i = 15000 \text{ mt}$$


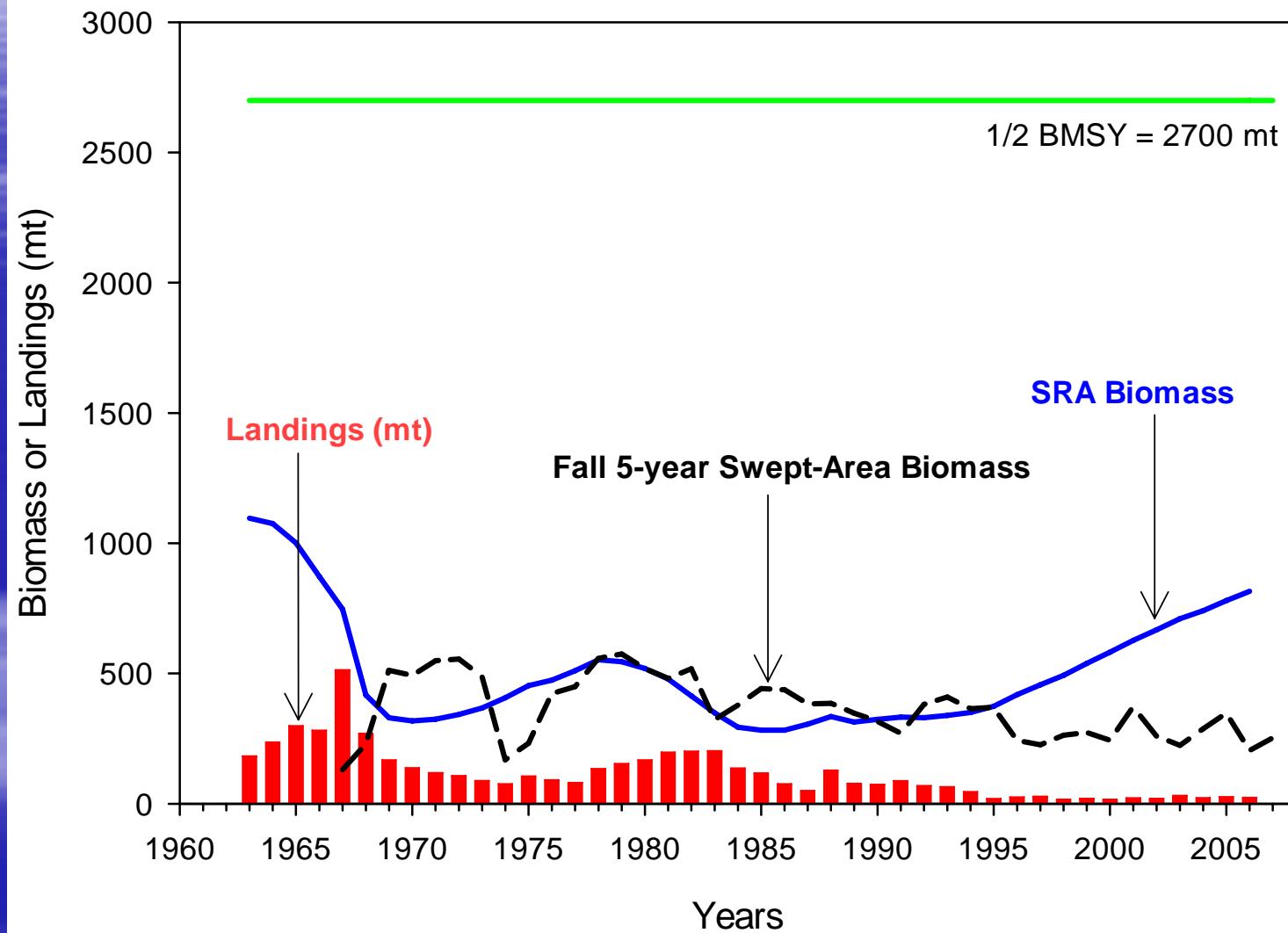
Atlantic Halibut Biomass from Stock Reduction Analysis

$$B_i = 7000 \text{ mt}$$



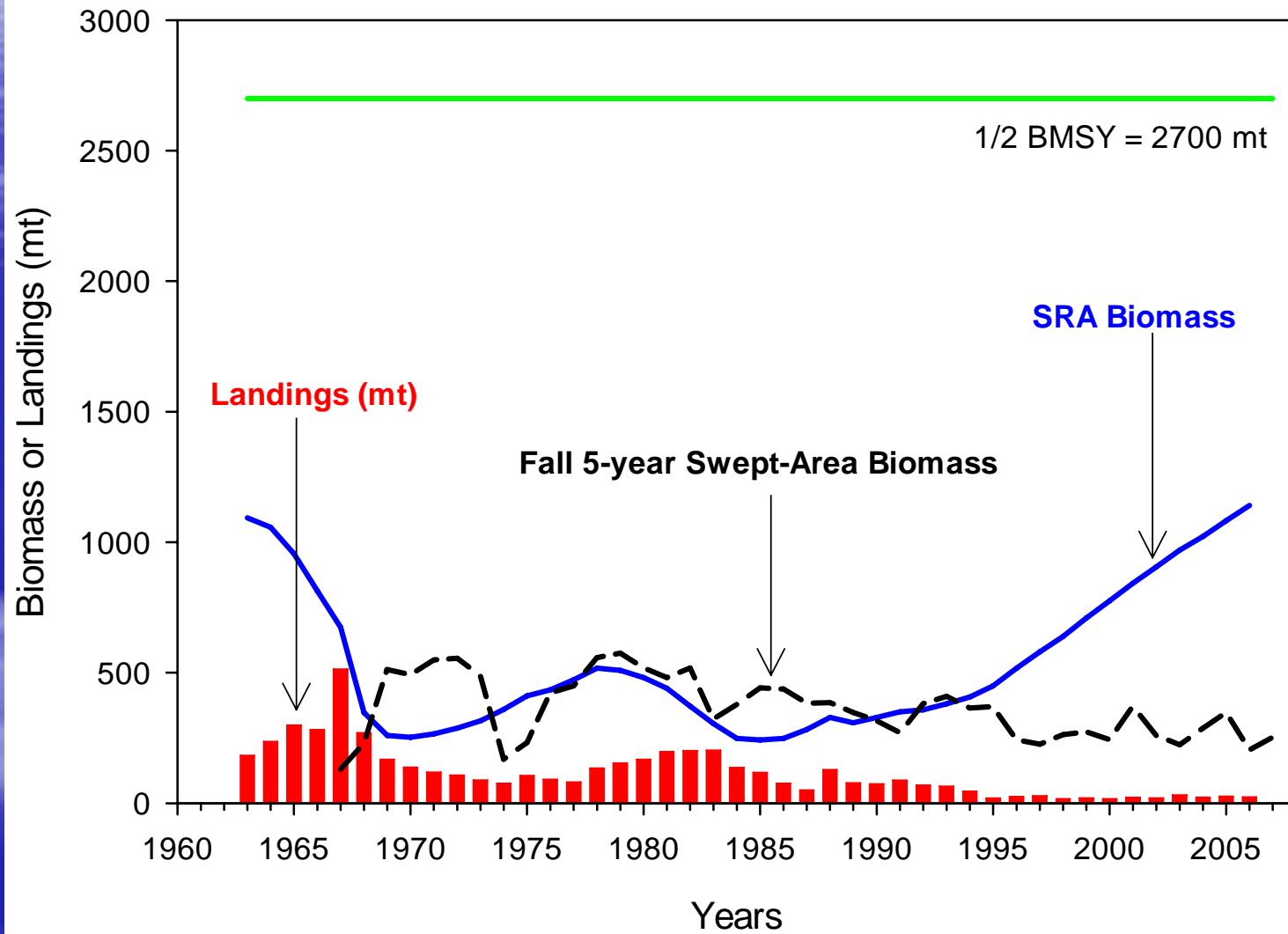
Atlantic Halibut Biomass from Stock Reduction Analysis

$$B_i = 11000 \text{ mt}$$



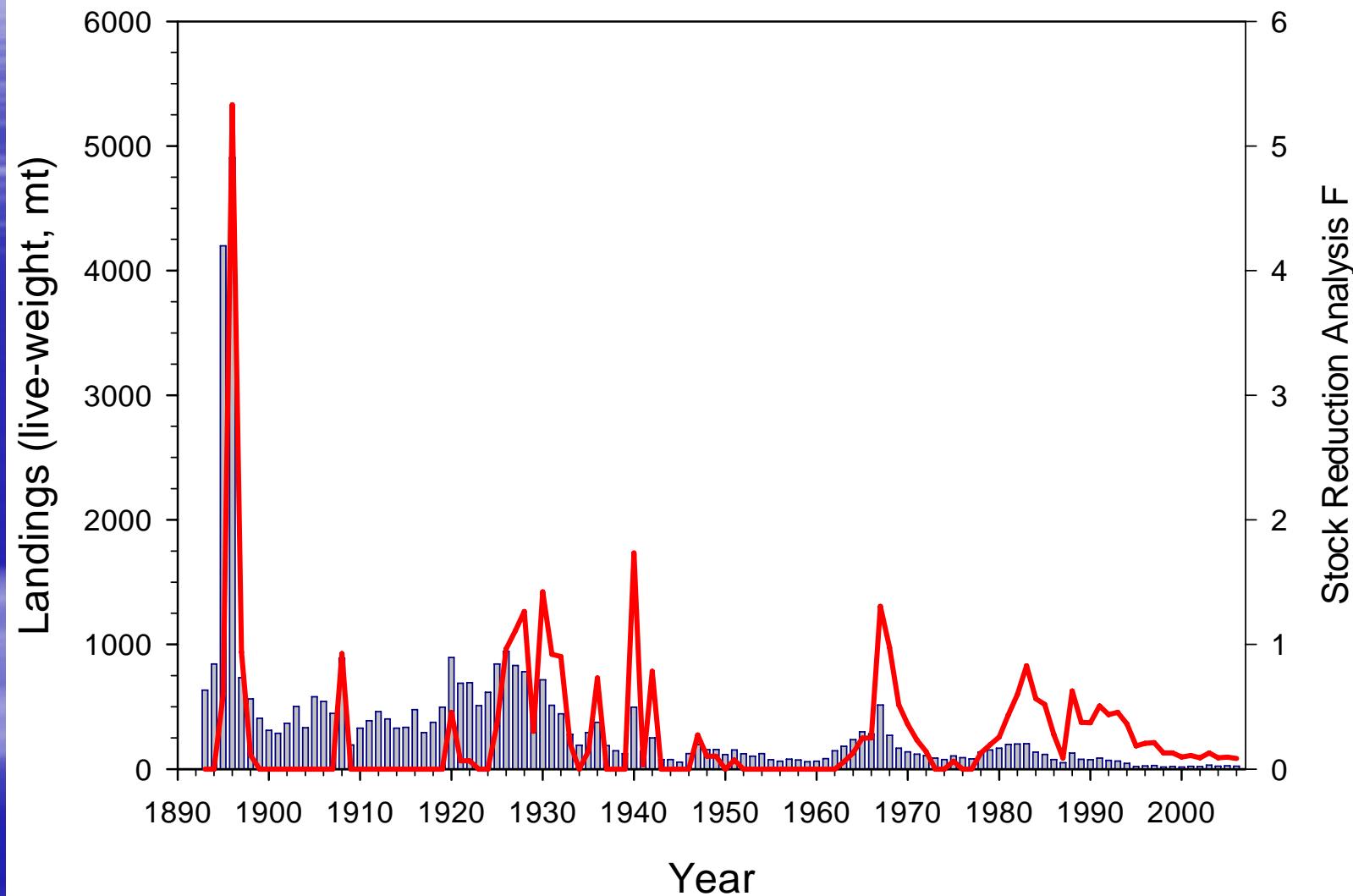
Atlantic Halibut Biomass from Stock Reduction Analysis

$$B_i = 15000 \text{ mt}$$



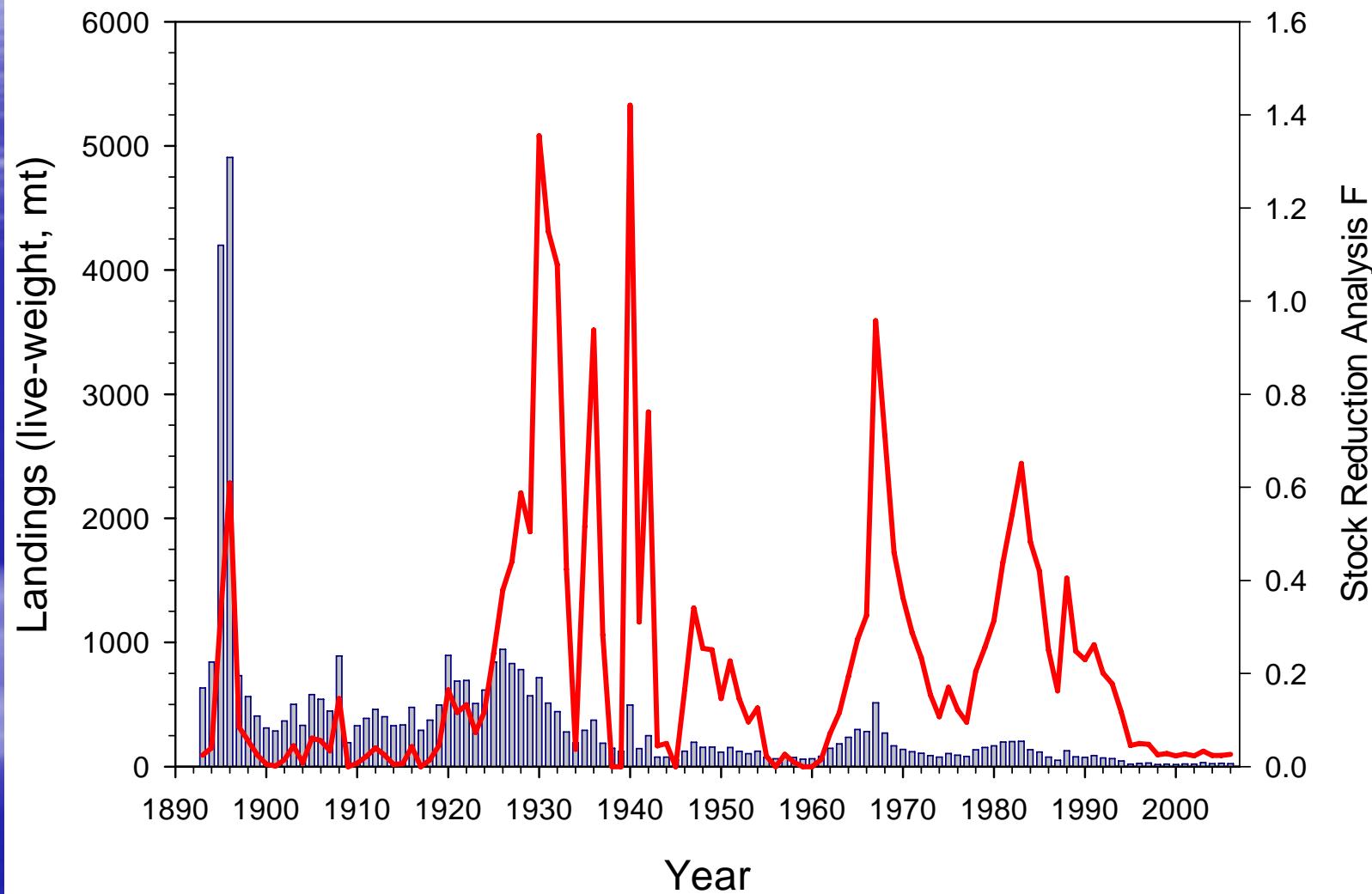
Atlantic Halibut Fishing Mortality from Stock Reduction Analysis

$$B_i = 7000 \text{ mt}$$

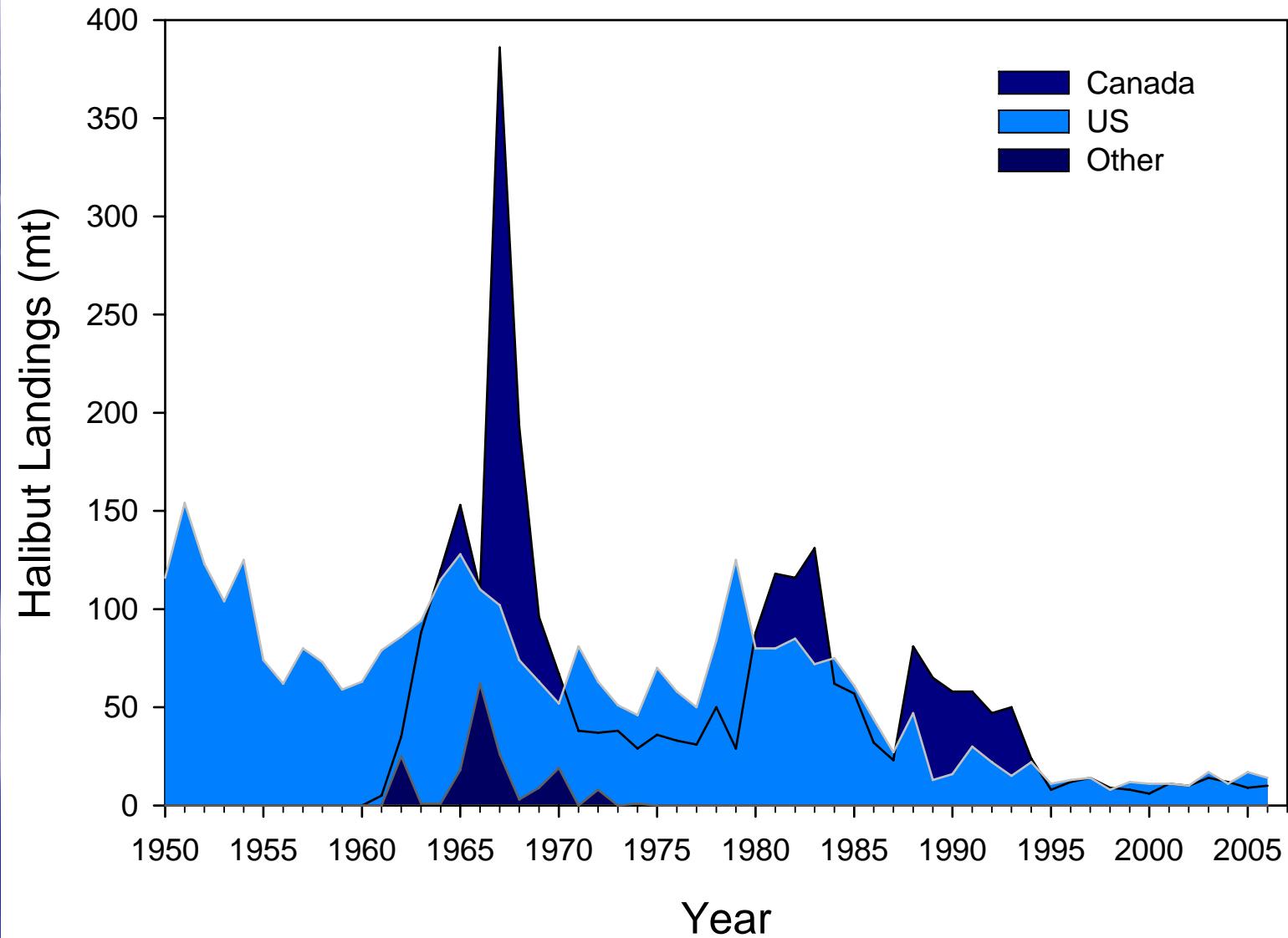


Atlantic Halibut Fishing Mortality from Stock Reduction Analysis

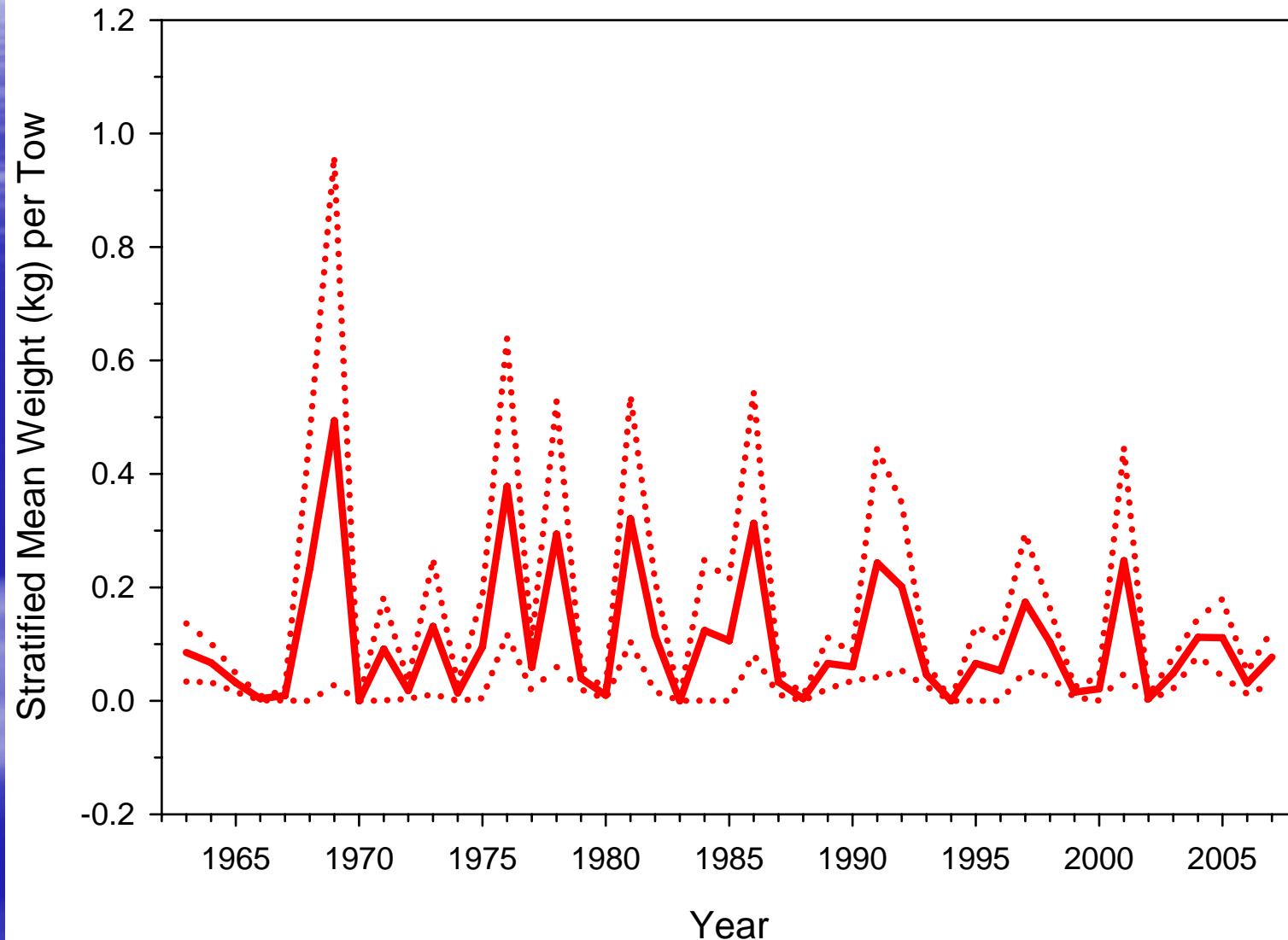
$$B_i = 15000 \text{ mt}$$



Atlantic Halibut Landings



Atlantic halibut NEFSC autumn biomass indices
(stratified mean weight per tow) with 1 standard error



Atlantic halibut NEFSC spring biomass indices
(stratified mean weight per tow) with 1 standard error

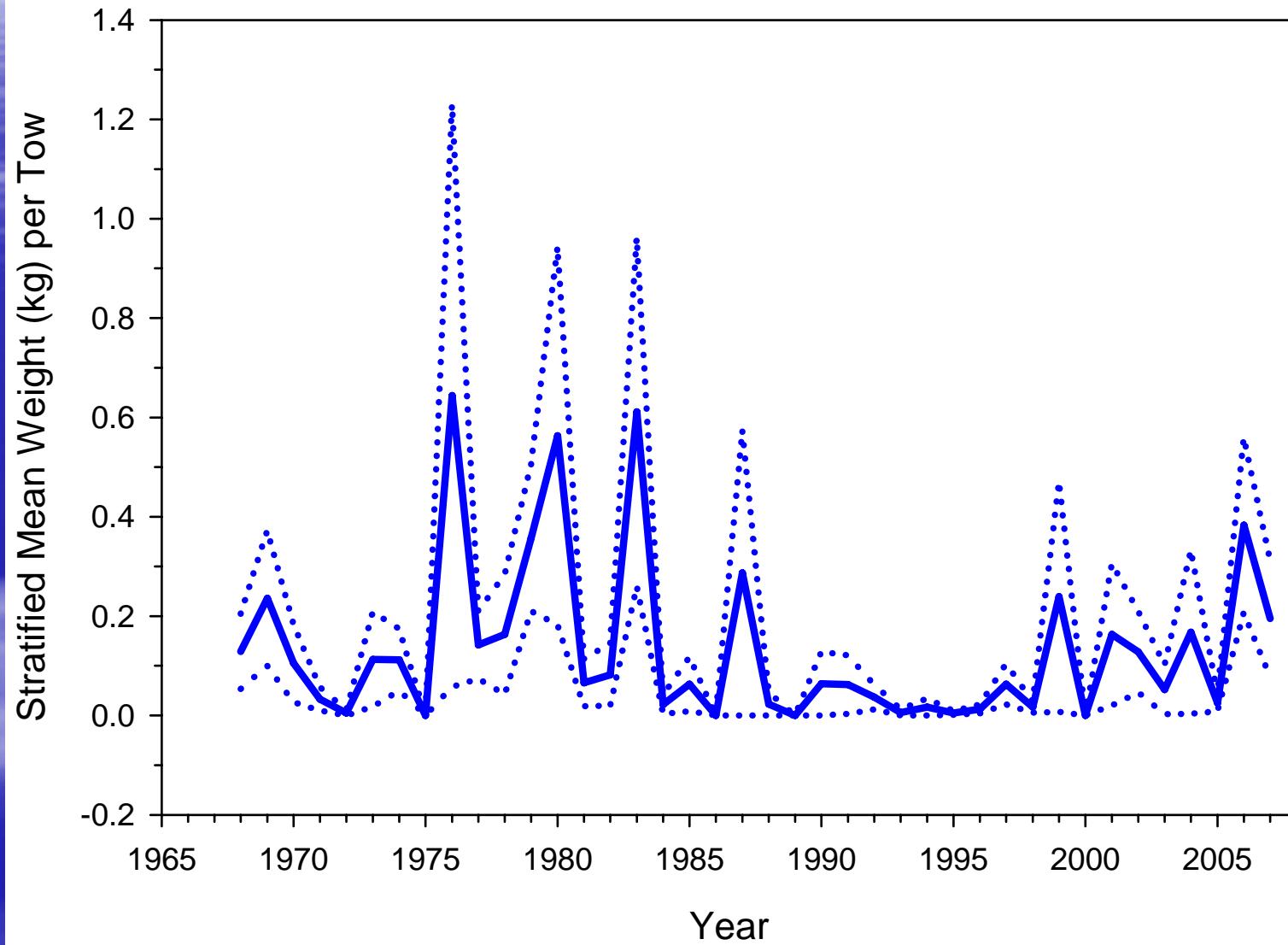
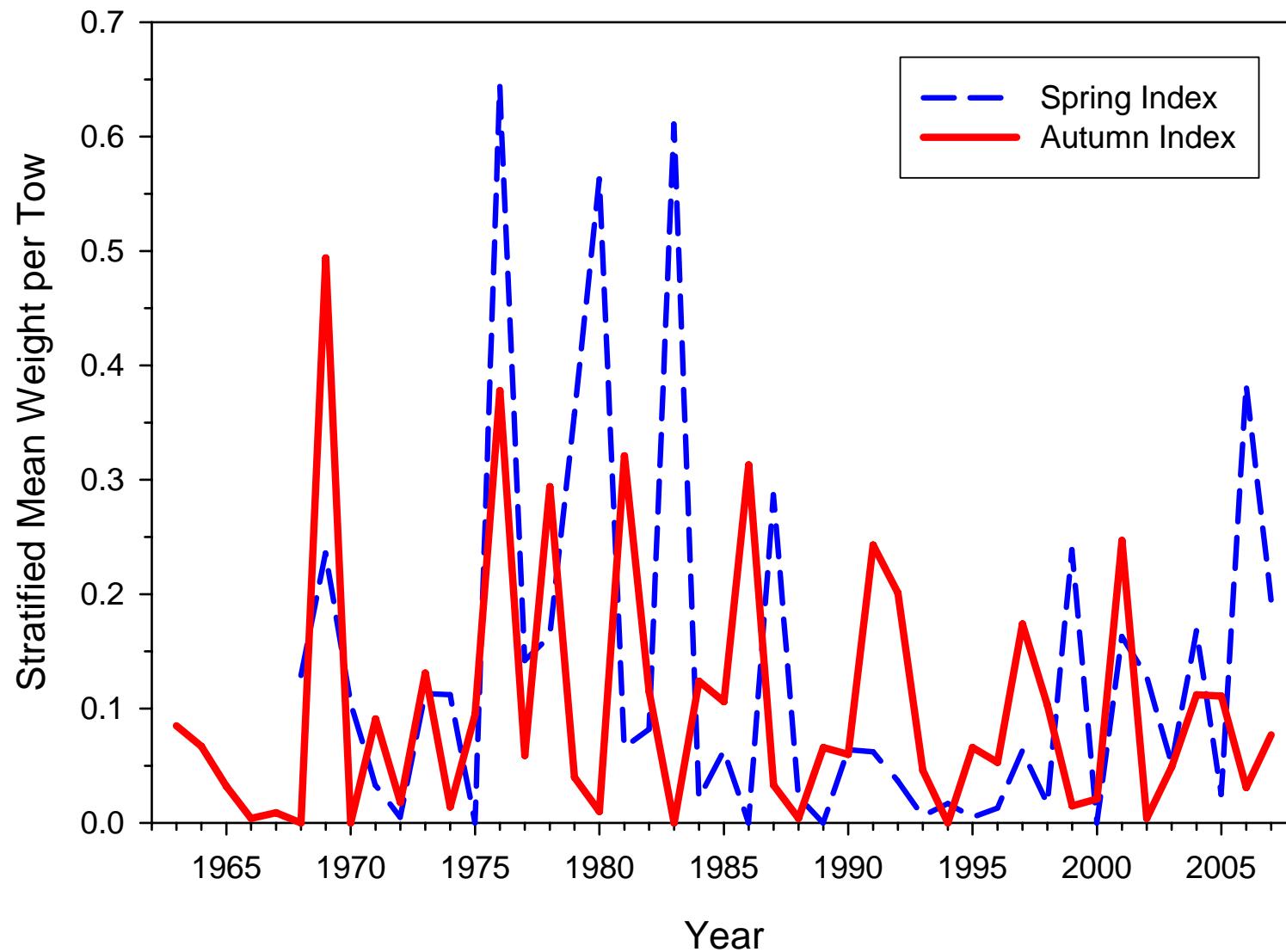


Figure S3. Atlantic halibut biomass indices (stratified mean weight per tow) from NEFSC spring and autumn surveys.



Use of Spring v. Autumn Survey Index

Time Series

- Autumn survey has longer time series
- Autumn survey includes relatively high landings during 1963-1967 (highest landings since 1930s)

Variability

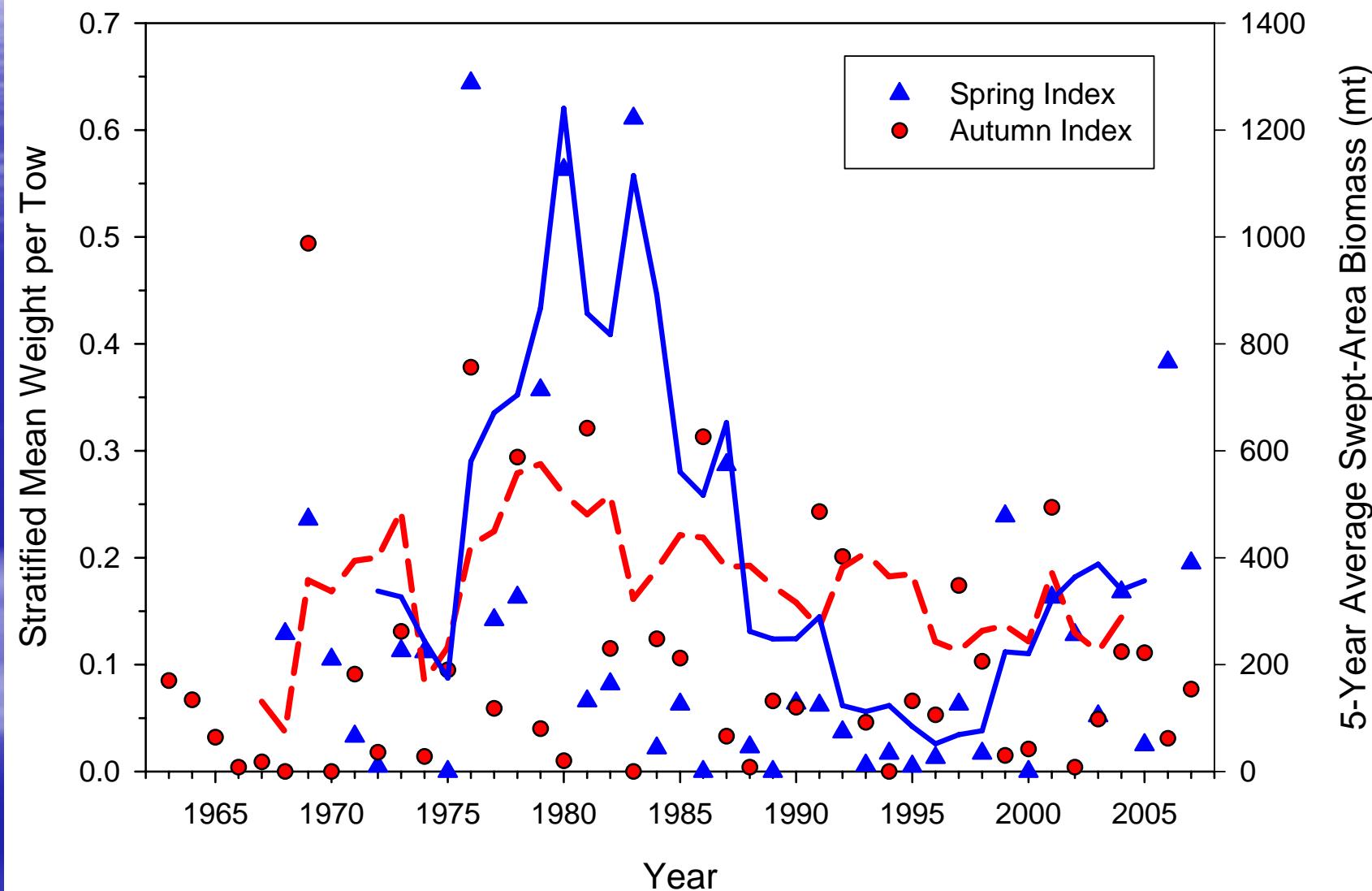
- CVs/SE similar between surveys
- Similar number of years with 0 halibut
- Similar number of total halibut caught

Temperature Correlation in Spring Survey

- Spring swept-area biomass neg. corr. with spring bottom water temperature anomalies
- Water temp. influences spring distribution
 - Not seen in autumn survey

Atlantic Halibut

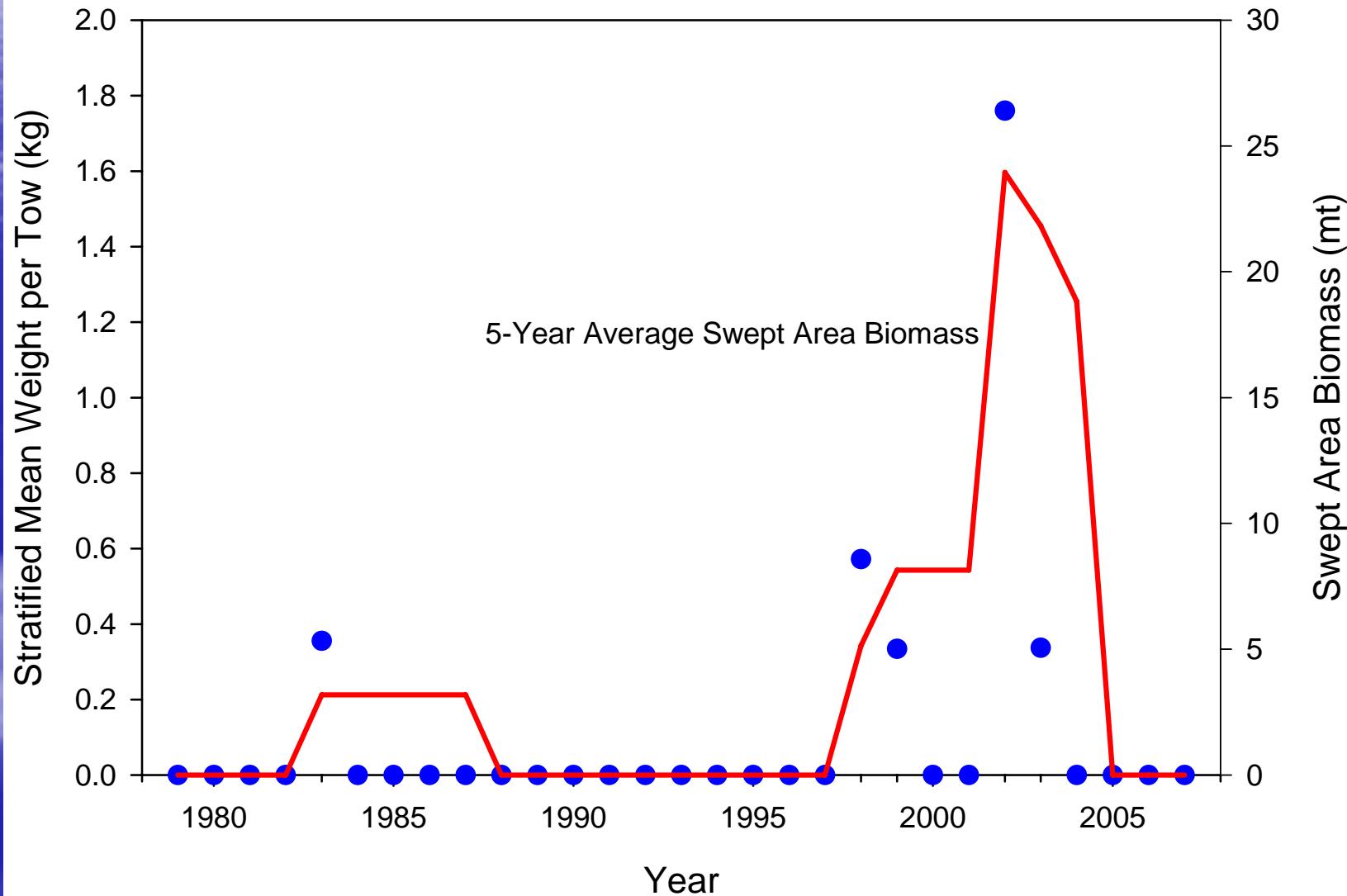
NEFSC Spring and Autumn Survey Indices and Swept-Area Biomass



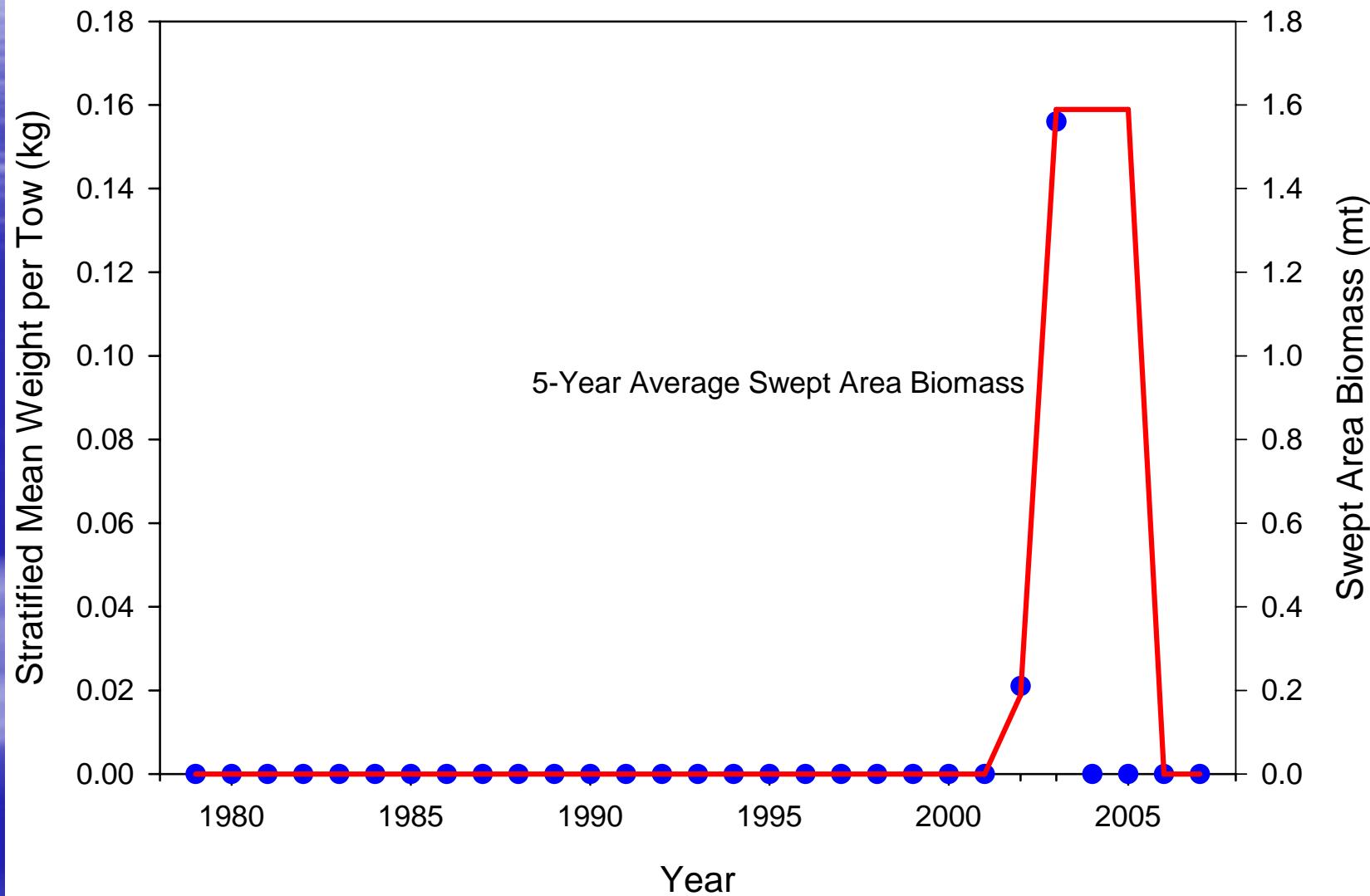
Discarded Halibut				Kept Halibut			
Year	Mean Length (cm)	Std Err	N	Year	Mean Length (cm)	Std Err	N
1990	.	.	.	1990	46.6	2.0012	6
1991	.	.	.	1991	92.0	.	1
1992	33.0	.	1	1992	67.1	5.2457	11
1993	31.3	13.3458	3	1993	62.8	5.5333	10
1994	42.4	5.1049	5	1994	73.3	5.0781	16
1995	27.2	5.4858	6	1995	79.6	4.6356	29
1996	.	.	.	1996	69.2	10.027	5
1997	36.3	2.1858	3	1997	67.5	11.3893	6
1998	.	.	.	1998	.	.	.
1999	62.0	.	1	1999*	.	.	.
2000	57.0	4.0778	13	2000	.	.	.
2001	67.5	2.9518	13	2001	118.0	6	2
2002	70.2	4.7648	13	2002	88.0	9.0738	6
2003	64.0	1.6363	91	2003	81.0	5.349	29
2004	57.1	1.3502	87	2004	83.9	3.9709	33
2005	60.4	1.3042	160	2005	76.4	2.5691	80
2006	63.0	1.495	107	2006	84.9	3.5611	37
2007	64.0	2.0581	70	2007	89.4	4.7544	29

*Minimum size of 91cm implemented in 1999

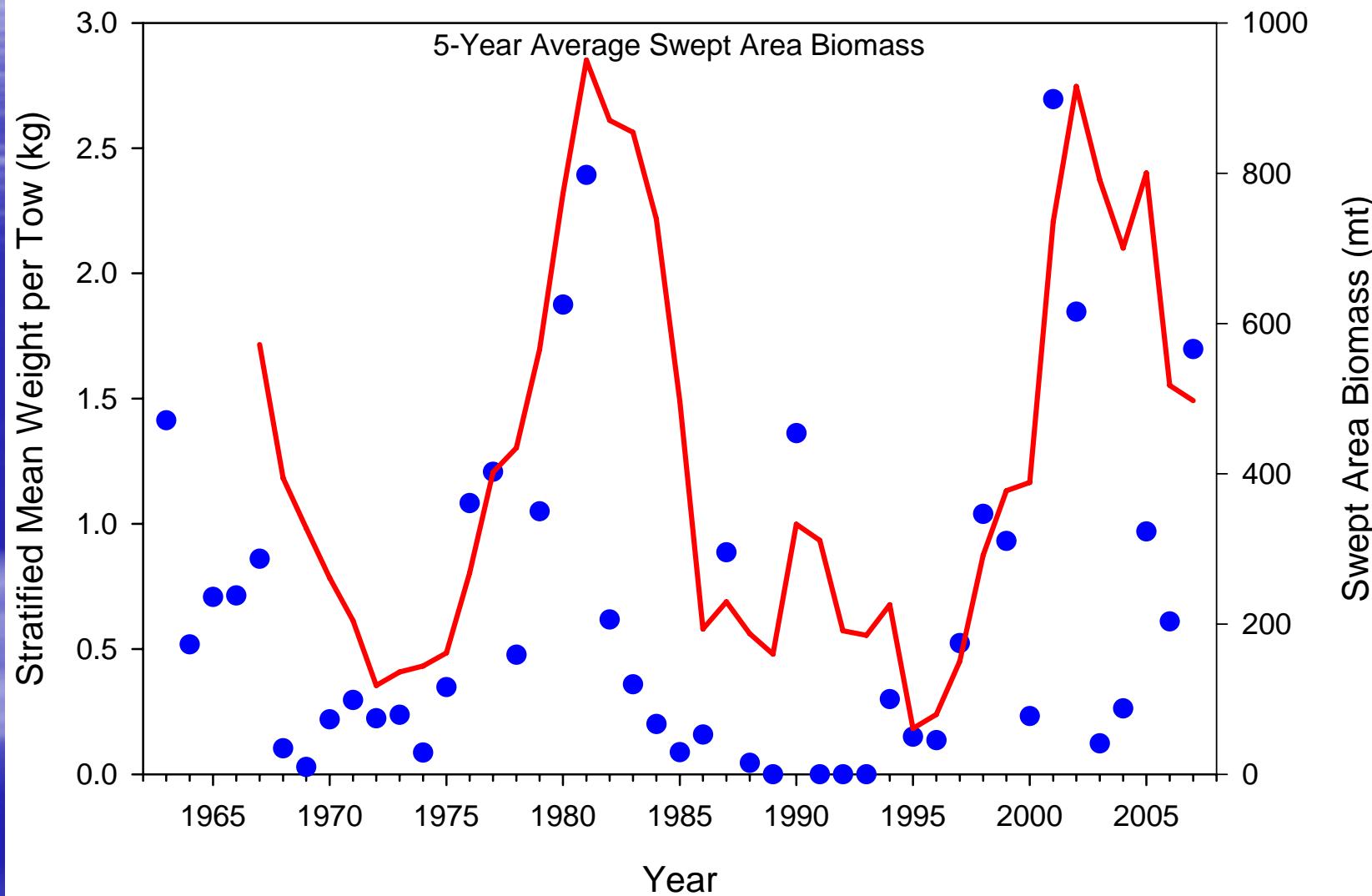
NMFS Fall Survey Halibut in Massachusetts Inshore Strata



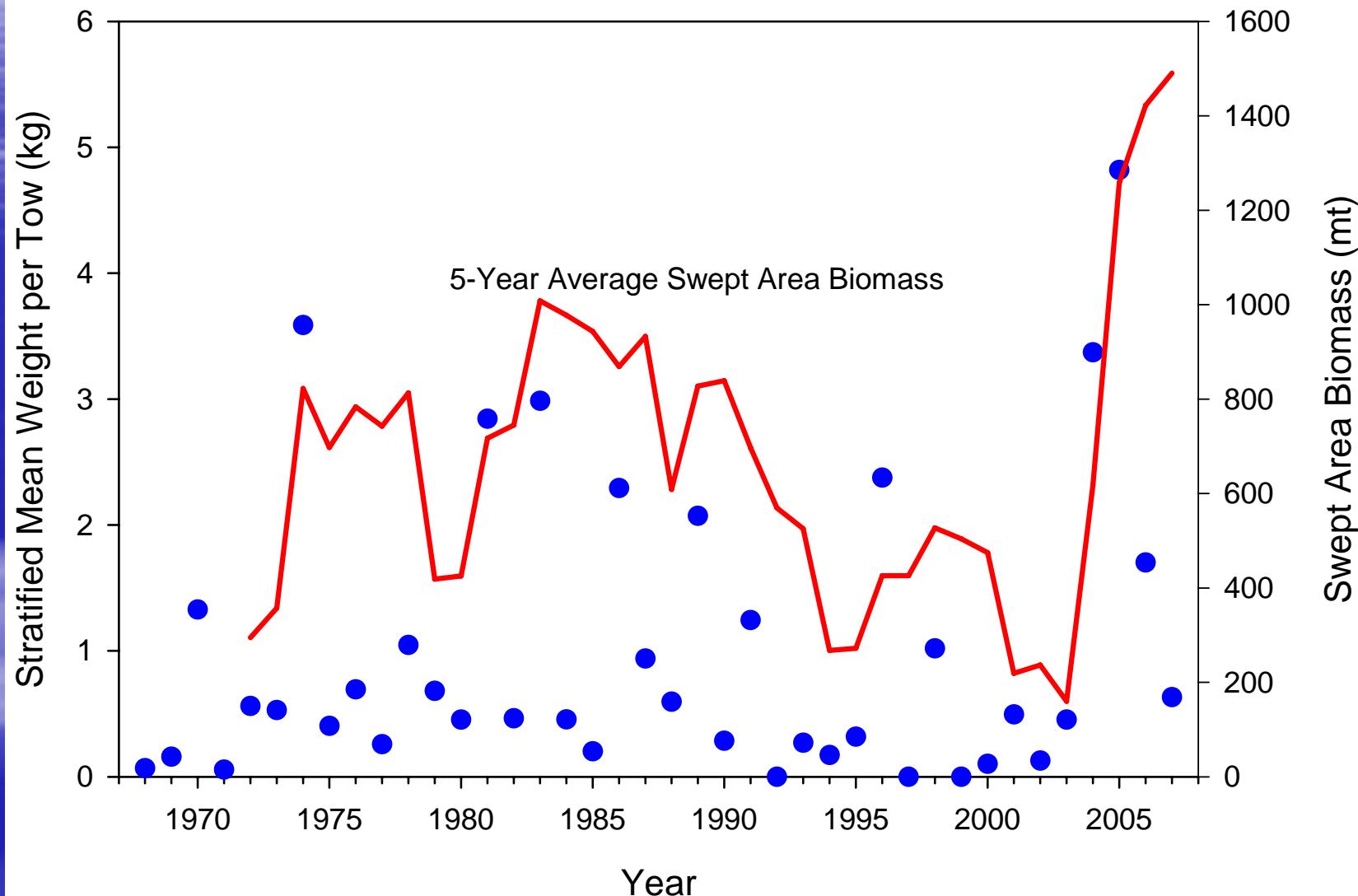
NMFS Spring Survey Halibut in Massachusetts Inshore Strata



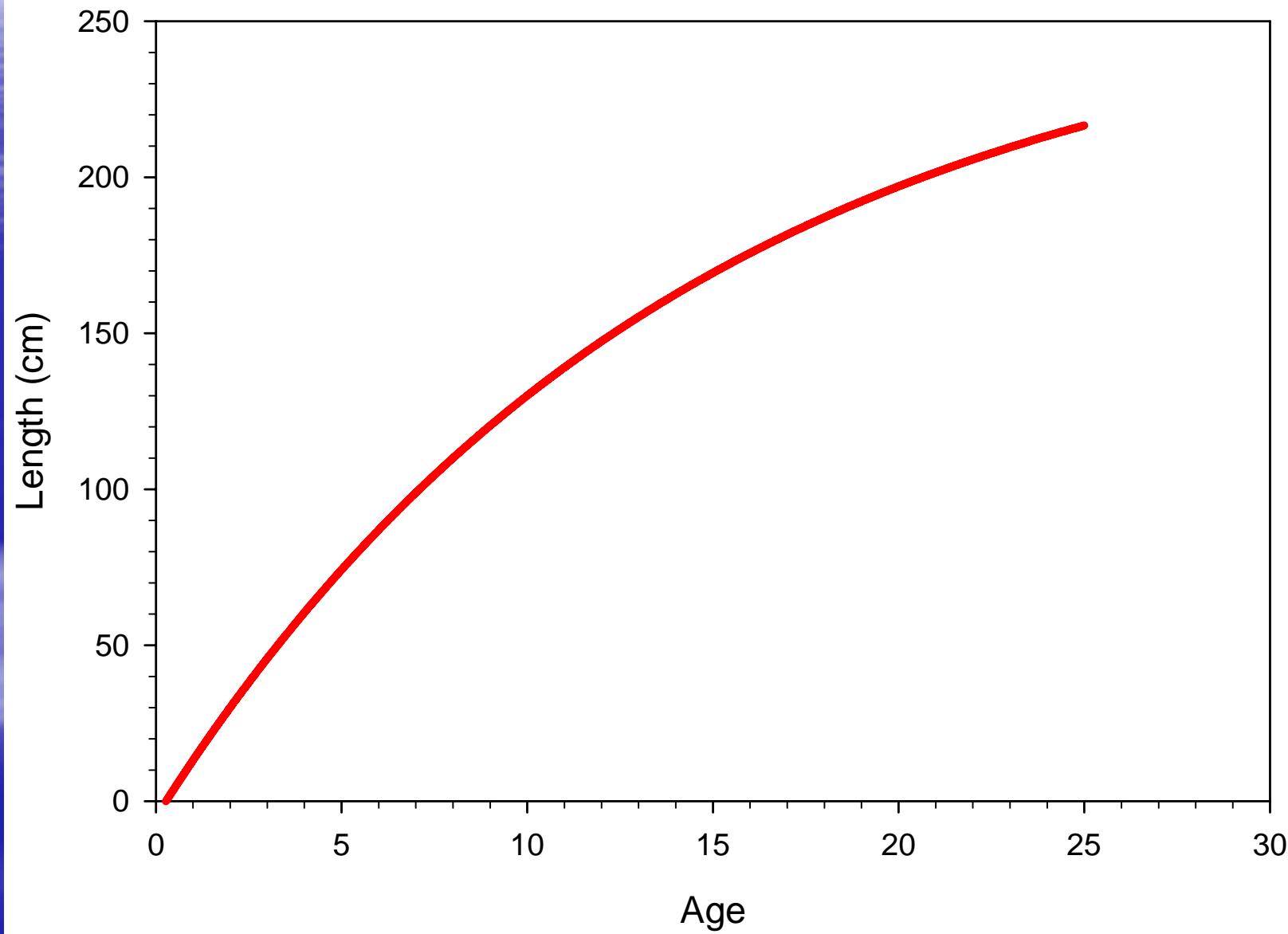
NMFS Fall Survey Scotian Shelf Halibut



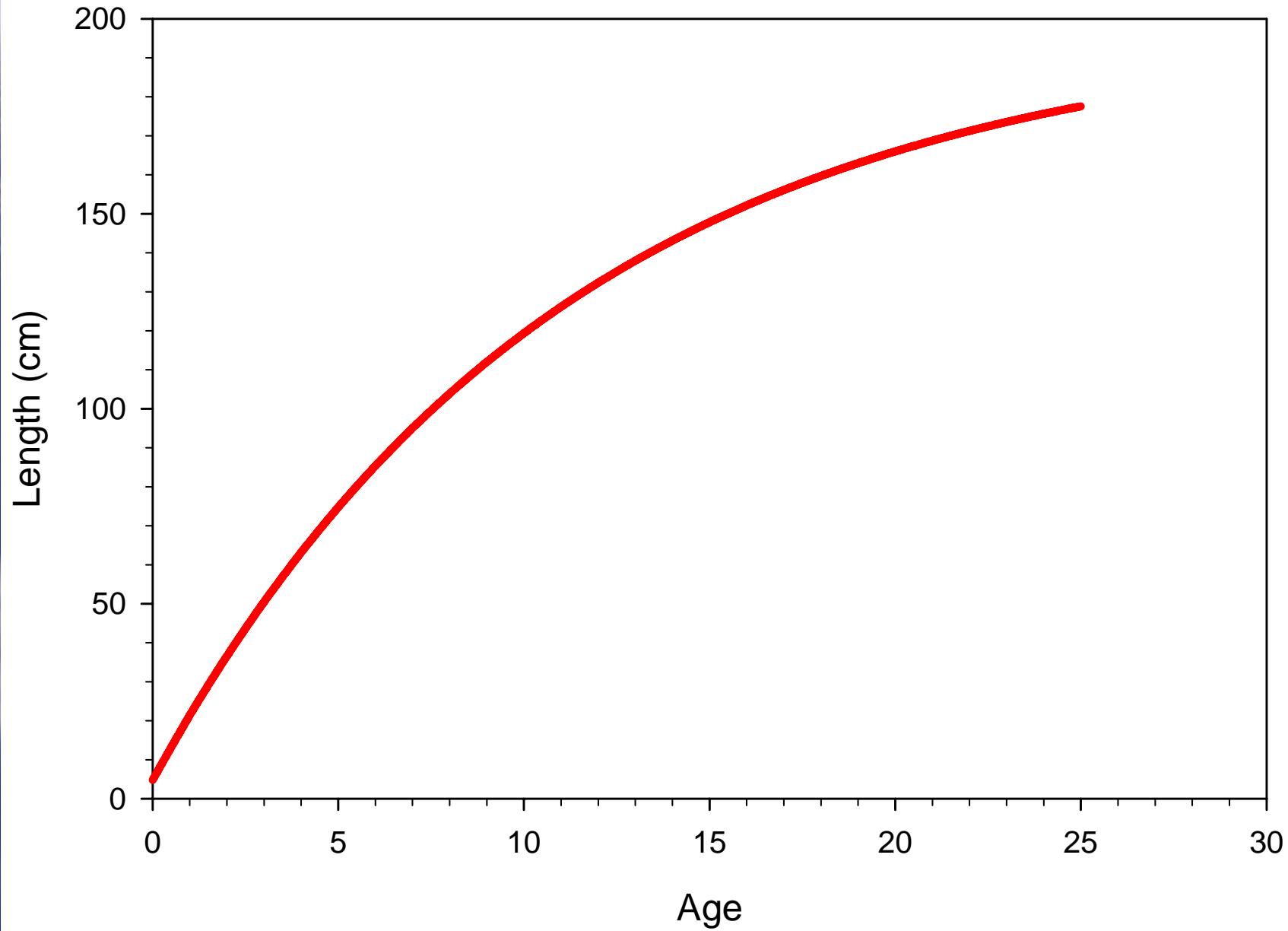
NMFS Spring Survey Scotian Shelf Halibut



Halibut von Bertalanffy Growth Curve Pooled Data Females



Halibut von Bertalanffy Growth Curve Pooled Data Males



Atlantic Halibut

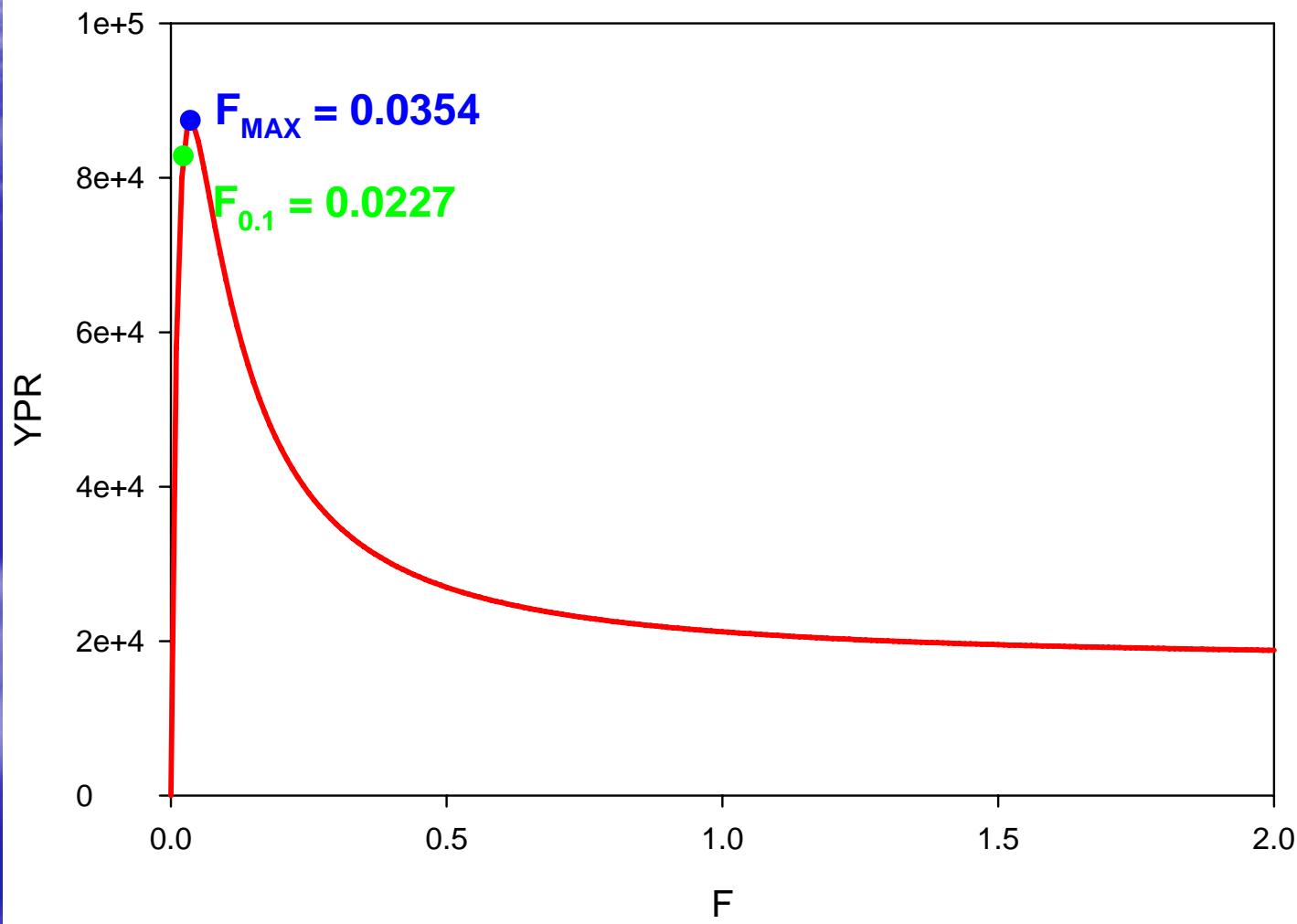
	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	D
Landings	●	●	●	●	●	●	●	●	●	○	○	○	○	○	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	5.616			
Discards																																						10.444								
Autumn Survey Exploitation Index						●	●	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	17.244							
NEFSC Autumn Survey	○	○	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	7.313								
NEFSC Spring Survey											●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	6.834					
Autumn Survey 5 Year Average Swept-Area Biomass										●	●	○	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	1.399	

Legend

● Highest ● 2nd Highest ○ Middle ● 2nd Lowest ● Lowest

D = Measure of Dispersion: Range/Median

Halibut Yield per Recruit Female Pooled



Halibut Spawning Stock Biomass per Recruit Female Pooled

